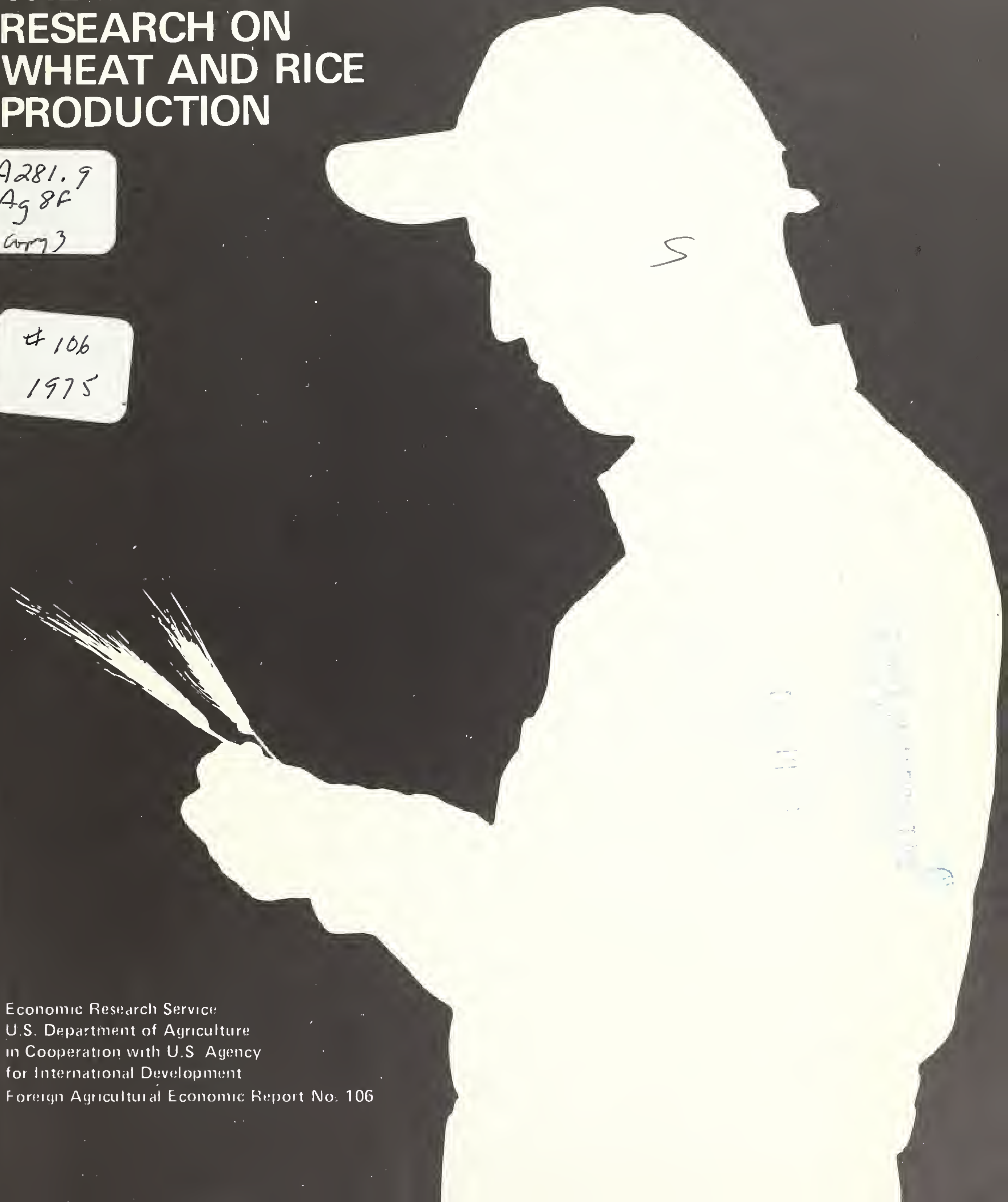
MEASURING THE GREEN REVOLUTION: THE IMPACT OF RESEARCH ON WHEAT AND RICE PRODUCTION



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ABSTRACT

Internationally sponsored agricultural research for the developing nations began when the International Rice Research Institute in the Philippines was established in 1962; as of early 1975, such research had grown to include six active international institutes, three more under development, and two related programs. The 1975 budget for all of the activities, which are under the aegis of the Consultative Group on International Agricultural Research, was about $48 million.

This report reviews the main considerations in evaluating effects of the international research program on crop production in developing nations. It focuses on two crops, high-yielding varieties of wheat and rice. Direct and indirect effects on output are outlined and the problems of linking research with changes in production are cited. Several major approaches to measurement are then examined. First, changes in area and yield in countries adopting the high-yielding varieties are explored. Next, two more complex tools for assessing the effect on production—production function and index number analysis—are outlined. Calculations of the possible increase in wheat and rice production in Asia in 1972/73 are provided to illustrate these methodological tools.

The report concludes that quantitative measurement of the effects of international agricultural research cannot be comprehensive as yet, but that improvements in measurement are possible if more resources are devoted to the task.

KEY WORDS: Wheat, Rice, Agricultural research, Green revolution, High-yielding grain varieties, Agricultural development, Developing countries.

Cover: Norman Borlaug, in his customary baseball cap, examines new varieties of wheat at the International Maize and Wheat Improvement Center, Mexico.

Back Cover: Rice breeding work at the International Rice Research Institute.

PICTURE CREDITS

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Rockefeller Foundation: Photo 2

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PREFACE

This report was originally prepared for the Conference on Resource Allocation and Productivity in International Agricultural Research (referred to here as RC) held at Airlie House, Warrenton, Va., in January 1975. The conference was sponsored by the Agricultural Development Council (as part of its AID-funded Research and Training Network Program) and the World Bank. A summary report of the Conference will be published by the Agricultural Development Council in September 1975.

The conference brought together a wide range of agricultural scientists, economists, and administrators. Hence this study was organized and written for a rather broad professional group. The report represents a revision of the paper presented at the conference ("Impact of the International Institutes on Crop Production").

In making revisions, I have benefited from review of other conference papers, discussions at the conference, and comments by other participants. Earlier versions were reviewed by Guy Baird of AID, Robert Herdt of IRRI, and Don Winkelmann of CIMMYT. Vernon Ruttan of the Agricultural Development Council, conference chairman, suggested the topic and G. Edward Schuh of Purdue University served as discussant. Errors and oversights undoubtedly remain, for which I am solely responsible.

Funding for the study was provided principally by the Technical Assistance Bureau of the Agency for International Development through a Participating Agency Service Agreement with the U.S. Department of Agriculture. The report is companion to a previous AID-sponsored report on *Development and Spread of High-yielding Varieties of Wheat and Rice in the Less Developed Nations* (USDA, ERS, FAER No. 95, July 1974, 77 pp.)

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CONTENTS

SUMMARY

International agricultural research for less developed countries (LDC's) is assuming significant proportions; the 1975 budget for the Consultative Group on International Agricultural Research is about $48 million. Such levels of investment may well lead to a call for quantitative evaluation of the research results.

This report outlines the factors to be considered in evaluating the effects of international research, and explores some techniques for measuring the effects of high-yielding varieties (HYV's) in improving yield and production in the LDC's. It focuses on wheat and rice.

A brief introduction to the international agricultural research institutes emphasizes the centers which concentrate on the two crops studied in this report: the International Maize and Wheat Improvement Center (CIMMYT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines.

The key institute products are the high-yielding varieties and a package of associated inputs. Besides direct quantitative effects (such as increasing yield) these improved varietites can have direct qualitative effects (such as improving nutrition) and indirect effects (such as allowing multiple cropping). Although these are all significant, this study focuses on the direct quantitative effects, examining in detail the measurable effects on yield and production.

Many factors intervene between the development of a genetically improved variety that increases yield in an experiment station and the actual production changes in the farmers' fields. In many cases, the varieties are tailored to local conditions through local breeding and research programs. Furthermore, the HYV's normally need a package of associated input practices, such as increased fertilization, improved pest control, and usually irrigation, to reach full potential. Thus it is often difficult to sort out the differential effect of each of these factors. Many economic and social forces also affect the degree to which the potential increases are actually achieved.

Two intermediate measures of the impact of the HYV's are changes in area and yield. A comparison of area and yield in seven Asian nations where the HYV's have been most heavily adopted reveals that well over half of the increase in production was due to expansion in yields. This expansion, in turn, was associated with an increase in the portion of the area planted to HYV's.

Although national data confirm that yields of HYV's are well above traditional varieties, this comparison is limited because the land bases used for the surveys may differ. As might be expected, average HYV yields tend to drop off as the HYV areas expand, presumably into less favorable regions.

Relative yield levels are used, along with other data, to make more sophisticated quantitative measures of the effect the HYV package has on crop production. Two types of analytical techniques are used: production functions and index number analysis. Each approach has certain limitations, but these can be partly offset when they are used together. Use of the two techniques is demonstrated with empirical data for wheat and rice.

The production function approach is a statistical technique which can suggest the relative importance of various factors in influencing production. Two recent examples of production function analysis are reviewed. The work of Evenson for wheat and rice in Asia and North Africa for the 8-year period from 1965/66 to 1972/73 is of special relevance.

A simplified form of the index number approach is developed and applied to available data for wheat and rice in Asia in 1972/73. Assuming HYV yield improvements over traditional varieties of 25 percent for rice and 50 percent for wheat, the index number approach suggests that the overall increase in Asian production (excluding Communist Asia) was about

18 percent for wheat and 5 percent for rice. This was equivalent to 8.7 million metric tons of wheat and 7.7 million metric tons of rice. The gross value of this added production would have been about $1 billion.

When results of these two analytical methods are compared for 1972/73, the index number approach produces a more conservative estimate of production increases. Though the precise output estimates generated by the index number approach differ depending on yield assumptions, the technique can generate rough assessments fairly easily. Both types of analysis can be improved—in part by refining techniques and in part by improving the data.

Additional work is needed to measure the impact of international agricultural research more comprehensively and precisely, and to include institute products beyond wheat and rice. This report concludes by briefly reviewing the need for additional research and funding possibilities.

I. INTRODUCTION

Research on food crops in or for the less developed countries (LDC's) is relatively new. For decades, much of the agricultural research in LDC's focused on plantation or export crops. Food crops for domestic consumption were, with a few exceptions,[1*] ignored. The situation began to change in the years following World War II, but even then, national research on food crops was usually given low priority and limited funding.

There were some exceptions. Perhaps the best known exception is the cooperative program on food crops begun by the Rockefeller Foundation and the Mexican Government in 1943. This work led to new research programs in other Latin American countries in the 1950's.[2] Some other international cooperative research activities were carried out in the same decade—such as the rice hybridization project sponsored by the Food and Agriculture Organization in India.[3] And a few developed nations supported scattered institutional development and research programs in the LDC's. But most of the reseach on food crops continued to be done in the developed nations.[4]

A significant change took place in the early 1960's with the establishment of two international crop research institutes: The International Rice Research Institute (IRRI) in the Philippines and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico. These two institutes were located in LDC's and oriented to their food problems. Their early successes led to the establishment of a number of other international research activities. They also led to a rebirth of interest in improving and expanding national research programs. All of these activities were enhanced by earlier and concurrent programs of human and institutional development.[5]

As of the mid-1970's research on food crops in and for the LDC's is finally coming of age. A Consultative Group on International Agricultural Research (CG)—composed of nations, international organizations, and foundations—has been established.[6] The annual investment on international research through this group reached about $48 million in 1975. The U.S. Agency for International Development (AID) contributes up to 25 percent of the costs of CG-sponsored activities and will spend about $11 million in 1975.[7] In addition, AID is actively stepping up financial support for national research programs within LDC's.[8]

While the funds involved are substantially greater than those of a few years ago, they are miniscule in terms of the job to be done. They are also relatively small in terms of global expenditures for agricultural research in the developed nations or for other items of public expenditure.[9] But they do represent a significant addition to the total expenditure on agricultural research for developing nations.

Such an investment is likely to spur interest in measuring results. The technical products are abundant and are presented in considerable detail in the annual reports and other publications issued by the institutes. Economic and social aspects of the resulting technologies are also beginning to be studied in greater detail.

But the quantitative effect of institute efforts on actual production in the LDC's has not yet been closely examined. There are good reasons for this lag: the centers are new, such an analysis is very difficult, and few resources have been devoted to the task. Nevertheless, the field is not entirely unexplored. Some studies have been carried out in the past on the effect of national agricultural research programs, in both developed and less developed countries. Generally, the results have shown high rates of return to investment in research.[10]

The next step will be a more specific evaluation of the effects of international agricultural research. But to do so effectively will require more than knowledge of economics and quantitative tools. It will also require theoretical and empirical knowledge of:

—The nature of the international centers and the associated international agricultural research system.

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*Footnotes are grouped at the end of each chapter.

1. The International Maize and Wheat Improvement Center (CIMMYT) in El Batan, Mexico.

—The adoption process at the farm level for resulting agricultural technology.

—Available statistical data which help measure both the input into research and the effect of the product.

Some such knowledge presently exists, but it tends to be in fragmentary form. Dr. Robert Evenson and I have been separately involved in analyzing certain components for several years. His attention has been more heavily focused on fairly quantitative and aggregative analysis of agricultural research in general.[11] I, on the other hand, have been more concerned with analyzing specific technologies—and most recently have been involved in documenting the development, spread, and influence of the high-yielding varieties of wheat and rice.[12]

Both approaches are necessary for evaluating the impact of international research on crop production. But they are not quite sufficient. There is a need to find a middle ground where quantitative concepts and tools of measurement are more closely woven with empirical knowledge of the technology. And there is a need to blend highly aggregative analysis with studies which are somewhat more local. This report moves toward this middle ground.

It will first examine the general question of the various effects of research that must be considered in evaluating its impact, and then offer more specific and narrow quantitative analyses of the direct effects on yield and production. A precise and definitive measure of the effect of international research on wheat and rice production is not attempted; this, as will be demonstrated, is most difficult. Rather, conceptual and methodological problems involved in the process are introduced. Empirical data are used largely for illustrative purposes.

Though production changes can have important effects on economic and social factors, these matters were simply beyond the scope of this study. In any case, they have been discussed elsewhere.[13]

Much more work will be needed before the effects of international agricultural research can be comprehensively assessed. This report introduces some of the major considerations involved, and it should encourage further study of this most important subject.

References And Notes

[1] In India, systematic research on wheat was begun in 1905 by the Indian Agricultural Research Institute at Pusa and on rice in 1911 with the appointment of a Special Botanist in what was then the province of Bengal (Albert Howard and G.L.C. Howard, *The Improvement of Indian Wheat*, Agricultural Research Institute, Pusa, Bulletin No. 171, 1927, pp. 1-16; M. S. Swaminathan, "Preface," in *India's Rice Revolution, A Beginning; The Role of the All-India Coordinated Rice Improvement Project* [Hyderabad, 1974], p.i.). The early Indian research on wheat and rice, according to one writer, had little, if any, effect on actual production (Sidhir Sen, *A Richer Harvest; New Horizons for Developing Countries*, Orbis Books, New York, 1974, pp. 335-337). Research was begun on food crops in Taiwan early in the century but most of the increased production was destined for export to Japan (Raymond Christensen, *Taiwan's Agricultural Development: Its Relevance for Developing Countries Today*, U.S. Department of Agriculture, Foreign Agricultural Economic Report (FAER) No. 39, 1968, pp. 5-9, 29; Samuel P. S. Ho, "The Economic Development of Colonial Taiwan: Evidence and Interpretation," *Journal of Asian Studies*, February 1975, pp. 417-439).

[2] The origins and dimensions of this work are well reported in E. C. Stakman, Richard Bradfield, and P. C. Mangelsdorf, *Campaigns Against Hunger*, Belknap Press of Harvard University Press, Cambridge, 1967, 328 pp.; and Lennard Bickel, *Facing Starvation; Norman Borlaug and the Fight Against Hunger*, Readers Digest Press, New York, 1974, 376 pp.

[3] This was a joint program of the Indian Council of Agricultural Research and FAO. The work was conducted at the Central Rice Research Institute at Cuttack and was initiated in 1952. For background, see: Gove Hambidge, *The Story of FAO*, Van Nostrand, New York, 1955, pp. 145-148; *India's Rice Revolution, op cit.* p. ii.

[4] Although precise figures are not available, data compiled by Evenson suggest that of the total investment in *agricultural* research in 1958, about 90% was in the developed nations and approximately 10% was in the less developed nations (Robert Evenson, "Investment in Agricultural Research; A Survey Paper," prepared for the Consultative Group on International Agricultural Research, October 1973, p. 3). The proportions spent on *food* crops in the developing nations probably would have been even less.

[5] Many developed countries had for years provided training for LDC scientists. In addition, during the 1960's there was increased emphasis on developing agricultural colleges and research programs in the LDC's. AID, for example, helped sponsor a massive program of agricultural university development in India as well as the All-India Coordinated Rice Improvement Project (Hadley Reed, *Partners With India; Building Agricultural Universities*, University of Illinois, College of Agriculture, 1974, 159 pp.; Sen, *op. cit.*, pp. 326-335; *India's Rice Revolution, op. cit.*, 72 pp.).

[6] The Consultative Group was established in May 1971 under the auspices of the World Bank, Food and Agriculture Organization, and United Nations Development Program; it first provided funding for 1972. As of November 1974, there were 22 donor members: 4 international groups (United Nations Development Program, United Nations Environmental Fund, World Bank, and the Inter-American Development Bank), 14 nations, 3 U.S. foundations, and the International Development Research Center in Canada. Through 1974, all the national donors were developed countries; in 1975, Nigeria became the first LDC donor.

[7] The actual total may be slightly less due to the availability of other funds. In addition, AID contributed to the Asian Vegetable Research and Development Center in Taiwan. It also established a preliminary fund, along with a Canadian donor, for an International Fertilizer Development Center at the Tennessee Valley Authority in Muscle Shoals, Ala.; a more substantial contribution for initial operations is expected later in 1975.

[8] For example, AID made the following major multi-year research loans from FY 1971 through FY 1974: Brazil, $11.9 million; El Salvador, $4.5 million; Korea, $5.0 million; and Pakistan, $7.6 million. As of early 1975, it was processing or considering loans to: Indonesia, $5.4 million; Philippines, $5.0 million; Uruguay, $5.4 million; and Bangladesh, $6.56 million (including a $2.56 million grant component). A number of smaller project loans and grants are also in effect.

[9] Data compiled by Evenson (*op. cit.*, p. 3) suggest that the total expenditure on agricultural research in 1970 was $1.32 billion in the developed nations and $236 million in the developing nations, or a total of $1.56 billion.

[10] The earlier findings are summarized by Evenson, *op. cit.*, p. 20, table 5 (8 studies), and p. 22, table 6 (12 studies). More recent country investigations were reported at the Conference on Resource Allocation and Productivity in International Agricultural Research (RC) in January 1975: Reed Hertford, *et al.*, "Returns to Agricultural Research in Colombia," pp. 64-65, table 19; A. S. Kahlon and H. . Bal, "Returns to Investment in Agricultural Research in India; All India," p. 16, table 4; Yujiro Hayami and Masakatsu Akino, "Organization and Productivity of Agricultural Research Systems in Japan," p. 41, table 8; W. L. Peterson and J. C. Fitzharris, "The Organization and Productivity of the Federal-State Research System in the United States," p. 40, table 3; and Robert Evenson, "Comparative Evidence on Returns to Investment in National and International Research Institutions," p. 19a, table 5. (The Hayami and Akino paper was subsequently published in the *American Journal of Agricultural Economics*, February 1975; see p. 8, table 3.)

[11] Robert Evenson: (with Y. Kislev) "Research and Productivity in Wheat and Maize," *Journal of Political*

Economy, November/December 1973, pp. 1309-1329; "International Diffusion of Agrarian Technology," *Journal of Economic History*, March 1974, pp. 51-73; and "The Green Revolution in Recent Development Experience," *American Journal of Agricultural Economics*, May 1974, pp. 387-394. Also, Robert E. Evenson and Yoav Kislev, *Agricultural Research and Productivity*, Yale University Press, New Haven (June 1975), 275 pp.

[12] Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, U.S. Department of Agriculture, Economic Research Service, FAER No. 95, July 1974. 77 pp.

[13] A listing of some of the more important works is provided in Dalrymple, *op. cit.*, (July 1974), p. 2, fns. 2 and 3. The following more recent studies might also be added: Keith Griffin, *The Political Economy of Agrarian Change; An Essay on the Green Revolution*, Harvard University Press, Cambridge, 1974, 264 pp.; and *The Social and Economic Implications of Large-Scale Introduction of New Varieties of Foodgrain*, United Nations Research Institute for Social Development (Geneva), 1974, 55 pp.

II. THE INTERNATIONAL RESEARCH INSTITUTES

International agricultural research is done primarily under the aegis of the Consultative Group on International Agricultural Research (CG). As of early 1975, the CG was sponsoring six active international agricultural research institutes, three other institutes in varying stages of development,[1] and three related programs.[2]

The six active institutes were, in order of formal establishment:[3]

IRRI. International Rice Research Institute, Philippines

CIMMYT. International Maize and Wheat Improvement Center, Mexico

IITA. International Institute for Tropical Agriculture, Nigeria

CIAT. International Center for Tropical Agriculture, Colombia

CIP. International Potato Center, Peru

ICRISAT. International Center for Research in the Semi-Arid Tropics, India

In addition to these CG-sponsored activities, there are a few other programs of international agricultural research.[4]

2. The International Rice Research Institute (IRRI) in Los Banos, Philippines.

Background and Budget

Dates of establishment of the six active CG-sponsored institutes and the budgets for their programs are provided in table 1.[5] Total expenditures on core and capital (excluding special projects)[6] have grown significantly since 1968, and as of 1974 were $30.3 million. A substantial increase, to $42.3 million, was proposed for 1975. The total professional staff in 1974 was about 200, and was projected to climb to about 240 in 1975.[7]

Of the six institutes, only the first two have been in operation for 10 years or more. IITA and CIAT were organized in 1967 but did not begin full-scale operations until the early 1970's; both deal with a wider range of crops than IRRI or CIMMYT, and a little over one-third of CIAT's budget is devoted to livestock. CIP started in the early 1970's. ICRISAT is still in the process of developing its physical plant, but research is underway on five crops.

Because of the newness of the latter four institutes and the range of products covered, it is too early to assess their impact on crop production.[8] Therefore, this study focuses on two of the three crops covered by the first two institutes, rice and wheat. Corn is excluded. The work on corn has not, for a variety of reasons, been as successful as the work on the other two crops.[9] Any general study of the payoff to research should, of course, include the full range of efforts.

Table 1—Annual total expenditures (core and capital), six international agricultural research centers, 1959-75[1]

Year	IRRI	CIMMYT	IITA	CIAT	CIP[2]	ICRISAT	Total
				1,000 dollars			
1959	[3] 250	--	--	--	--	--	250
1960	[3] 7,060	--	--	--	--	--	7,060
1961	[3] 229	--	--	--	--	--	229
1962	[3] 405	--	--	--	--	--	405
1963	[3] 875	--	--	--	--	--	875
1964	[3] 625	([4])	--	--	--	--	625
1965	1,055	([4])	[5] 250	--	--	--	1,305
1966	1,125	457	[5] 350	--	--	--	1,932
1967	1,164	843	[5] 1,000	--	--	--	3,007
1968	1,641	1,427	[5] 1,034	51	--	--	4,153
1969	1,955	2,053	4,490	1,591	--	--	10,089
1970	2,135	5,017	4,505	2,143	--	--	13,800
1971	2,676	4,836	6,816	3,444	--	--	17,772
1972	2,960	4,942	6,397	4,317	492	342	19,450
1973	3,084	6,231	6,148	6,126	1,280	2,710	25,579
1974 (est.)	4,557	5,563	6,423	6,082	2,055	5,600	30,280
1975 (proposed)	8,520	6,834	[6] 8,394	5,828	2,403	10,250	42,229

[1] Except as noted, data refer to actual total expenditures. In most of the source tables for 1970-75, this category is referred to as "application of funds" (exclusive of funds carried over to the following year). It includes, in addition to funds obtained from the Consultative Group (CG), or individual donors prior to 1972, three other sources of "income": earned, indirect, and unexpended balances from the previous year. The totals therefore exceed, by these amounts, the annual funding requested from the CG. The totals exclude working capital and funds received and spent on special projects. The capital expenditures are generally for buildings and equipment; land is usually provided free by the host government. [2] Does not include facilities valued at about $600,000 provided by the Peruvian Government. [3] Grants received for capital and operating costs; not actual expenditures. [4] An International Center for Corn and Wheat Improvement was first formed in cooperation with the Mexican Government in late 1963 but was then reorganized and reestablished on an international basis as CIMMYT in 1966. [5] Funds granted by the Ford Foundation. In addition, $106,700 was provided by the Rockfeller Foundation from 1966 to 1968. Except for some site development from the end of 1966 until early 1968, the project was in suspension due to the civil war. [6] Revised estimate.

Sources:

1959-64 (IRRI). Letter from Faustino M. Salacup, Executive Officer and Treasurer, IRRI, August 28, 1974.

1965-69 (IRRI). Werner Kiene, Ford Foundation, August 1974.

1966-71 (CIMMYT). *This is CIMMYT*, CIMMYT Information Bulletin No. 8, March 1974, Chart 15/2, tables 1 and 2. Table 1 lists donors but really means expenditures (letter from Robert D. Osler, Deputy Director General and Treasurer, CIMMYT, September 11, 1974).

1965-70 (IITA). Letters from H. R. Albrecht, Director General, IITA, August 26, October 26, 1974.

1968-71 (CIAT). Letter from Andrew V. Urquhart, Controller, CIAT, August 29, 1974.

1970-75 (Except CIMMYT and CIAT, 1970, 1971; and IITA, 1975). Budget submissions or presentations for each center for 1974 and 1975, Table III. Estimates for 1975 for CIAT and ICRISAT modified on the basis of comments from Urquhart, *op. cit.*, October 22, 1974, and Ralph Cummings, Director, ICRISAT, September 14, 1974. CIMMYT and CIP figures include allowance for recent earthquake and flood damage. Revised budget figures for 1975 are expected to be higher.

1975 (IITA). Revised budget, including allowance for wage adjustment, circulated by CG, April 14, 1975.

Research on Wheat and Rice

Work leading to the eventual establishment of CIMMYT began in 1943 with the establishment of a grain program in Mexico by the Rockefeller Foundation, in cooperation with the Office of Special Studies of the Mexican Ministry of Agriculture. In 1959, Dr. Norman Borlaug became director of the Rockefeller Foundation's International Wheat Improvement Project. The wheat program was merged with a comparable corn program in October 1963 to form the International Center for Corn and Wheat Improvement.[10] By early 1966:

> . . .the growing demands on this program by the ever-widening food gap around the world indicated the need for a restructuring and expansion of activities. As a result, the center was reorganized and established on April 12, 1966, in accordance with Mexican law, as a nonprofit scientific and educational institution. . .to be governed by an international board of directors.[11]

The new board held its first meeting in September 1966 and approved programs for 1967. Major financial support was at first provided by the Ford and Rockefeller Foundations. In 1969, AID became a contributor. A new headquarters and laboratory facility were completed at El Batan (45 km. northeast of Mexico City) and dedicated on September 21, 1971. The initial construction cost of $3.5 million was provided by the Rockefeller Foundation;[12] through 1974, the total capital costs have been $6.4 million.[13]

In 1959, the Ford and Rockefeller Foundations jointly decided to establish a rice research insitute in the Philippines—IRRI. IRRI was formally organized on April 13 and 14, 1960, when its trustees met for the first time. Construction was finished in January 1962, and the institute was dedicated on February 7, 1962. By that time the research program was underway. The capital cost was $7.5 million.[14] Initially, Ford provided the physical plant and Rockefeller the operating funds; in 1965 they began to split the operating costs. AID support was added in 1970.

Since establishment, each center's program has grown somewhat beyond the crops indicated in their titles. On the other hand, some regional rice work has been taken up by CIAT and IITA.

The total amount proposed for actual expenditure on wheat and rice research in 1975, exclusive of related or overhead costs,[15] was:

Institute	Wheat	Rice	Total
		1,000 dollars	
CIMMYT	1,166		1,166
IRRI		2,380	2,380
IITA		225	225
CIAT		153	153
Total	1,166	2,758	3,924

Even if a prorated portion of the other costs were assigned to two crops and special projects added, the totals would probably not be over $10 million. The annual total would have been less in previous years.

Hence, when evaluating the impact of the international centers on wheat and rice production in the LDC's, the benefits can be compared with a relatively small investment over a short period.[16] In relation to the annual values of the crops involved, the expenditures on research are miniscule indeed.

Relation to National Programs

Throughout their history, IRRI and CIMMYT have been very closely involved with national LDC programs. As Hardin and Collins have noted, these centers "were not designed to supplant country efforts, but indeed were developed to complement and stimulate national research programs."[17] The nature of these institutional ties is amply described in the annual reports of the centers and in other papers.[18]

In addition to receiving funds from the CG, the centers' scientists carry out a substantial array of specially funded national projects. The first annual budget for CIMMYT in 1967 contained, for example, a $230,000 grant from the Ford Foundation for a Pakistan wheat project. Many such projects are currently underway, both by CIMMYT and IRRI.[19]

Further research is conducted by developed nations for international use. This includes AID-sponsored programs such as the University of Nebraska project to improve the nutritional quality of wheat, or the Mississippi State College project to help LDC's increase their capability to provide improved seed.[20] The CG is now giving additional attention to documenting these activities and to improving linkages with other research efforts.

Research activities carried out at the international centers, therefore, have close ties with research programs in both the developed and less developed nations. They provide a key link in a synergistic international agricultural research network.

References and Notes

[1] Two were in the process of building laboratories and other structures: ILRAD, the International Laboratory for Research on Animal Diseases (Kenya) and ILCA, the International Livestock Center for Africa (Ethiopia). ICARDA, the International Center for Agricultural Research in the Dry Areas, was being established in Lebanon and Syria. In addition, an international plant nutrition institute was under active consideration. Details on ILCA and ILRAD are provided in *International Research in Agriculture*, Consultative Group, 1974, pp. 64-70.

[2] They are IBPGR, the International Board for Plant Genetic Resources; WARDA, the West African Rice Development Association; and CARIS, the Current Agricultural Research Information System. WARDA, while involved in variety testing, has not yet become involved in research.

[3] Details on the programs of these centers, as of 1974, are provided in *International Research*, *op. cit.*, pp. 16-63.

[4] This category might include, for instance: AVRDC, the Asian Vegetable Research and Development Center, in Taiwan; and some regional programs such as CATIE, the Centro Agronomico Tropical de Investigacion y Ensenanaza, in Costa Rica. An International Food Policy Research Institute was in the process of being established in Washington, D.C. in early 1975.

[5] One should not, of course, total the columns for the individual institutes without making at least an allowance for inflation. Barker, in cumulating expenditures at IRRI from 1960 to 1972, used a GNP deflater and then went on to include a discount factor equivalent to an interest rate charge for the use of money over the period. The unadjusted total was $24.3 million; allowance for inflation raised it to $28.6 million; and addition of the discount factor raised the total to $51.6 million. (Unpublished table provided by Randolph Barker, November 29, 1973.)

[6] Special projects are excluded here because (a) they are funded outside of the CG, and (b) they are usually country-specific programs which may have a strong outreach or extension component. In a few cases, however, they may differ little from restricted core budget items.

[7] "Draft Integrative Paper," Consultative Group on International Agricultural Research, July 24, 1974, p. 3.

[8] Evenson places the mean time lag between expenditures on research and effect on production in the United States at about 6½ years (Robert Evenson, "Investment in Agricultural Research; A Survey Paper," prepared for the Consultative Group on International Agricultural Research, October 1973, p. 18).

[9] Corn, in many ways, is a more difficult plant to work with. Hybrids were developed, but it was found necessary to produce specific hybrids for each of the many different areas of the country, whereas a single wheat variety was found suited to large areas. Moreover, since corn is an open pollinated plant, new seed has to be purchased each year. These and other problems are discussed in Delbert T. Myren, "The Rockefeller Foundation Program in Corn and Wheat in Mexico," in *Subsistence Agriculture and Economic Development* (ed. by Clifton R. Wharton), Aldine Publishing Co., Chicago, 1969, pp. 438-452; and Dana G. Dalrymple, *New Cereal Varieties; Wheat and Corn in Mexico*, AID, Spring Review, May 1969, 32 pp.

[10] E. C. Stakman, Richard Bradfield and P. C. Mangelsdorf, *Campaigns Against Hunger*, Belknap Press of Harvard University Press, Cambridge, 1967, pp. 5, 12, and 273.

[11] *1966-67 Report, CIMMYT*, p. 9.

[12] See "CIMMYT's New Headquarters at El Batan," *CIMMYT Report*, Vol. 1. Nos. 1-6, November/December 1972, p. 1.

[13] Letter from Robert D. Osler, Deputy Director General and Treasurer, CIMMYT, September 11, 1974. The CIMMYT capital investment does not include housing for the staff. Also, when CIMMYT was legally constituted in 1966 it had acquired a number of vehicles and a fair amount of field equipment; the replacement of this equipment has been charged to operating costs and not to capital (Osler).

[14] Robert F. Chandler, "IRRI—The First Decade," *Rice, Science and Man* (Papers Presented at the Tenth Anniversary Celebration of the International Rice Research Institute, April 20 and 21, 1972), pp. 5-7. The IRRI capital cost included housing for staff.

[15] For the six centers in 1975, about 46 percent of the proposed core budget would actually go to research. The remainder would be broken down as follows: research support, 7 percent; conferences and training, 12 percent; library and documentation, 5 percent; general operations, 14 percent; general administration, 13 percent; and other 3 percent. In terms of the total proposed research budget for the six centers in 1975, wheat and rice would account for 27.7 percent of the total. ("Draft Integrative Paper," *op. cit*, p. 4, annex A.)

[16] As noted earlier, the work on wheat in Mexico goes back to 1943, but the annual expenditures by Rockefeller were relatively modest. The total annual expenditures on wheat research by the Office of Special Studies, converted from 1958-60 pesos, for 1954 to 1960 ranged from $345,000 to $203,000 (computed from data provided by Nicolas Ardito Barletta, "Costs and Social Benefits of Agricultural Research in Mexico," University of Chicago, Department of Economics, Ph.D. dissertation, 1970, p. 74).

[17]Lowell S. Hardin and Norman R. Collins, "International Agricultural Research: Organizing Themes and Issues," *Agricultural Administration*, 1974 (Vol. 1), p. 14.

[18]See particularly the papers prepared for the Conference on Resource Allocation and Productivity in International Agricultural Research (RC) by Burton Swanson, Nyle Brady, Haldore Hanson, and Sterling Wortman.

[19]In 1973, the cost of such projects carried out by CIMMYT totaled $1.8 million and included programs in more than a dozen countries; the Ford Foundation alone sponsored projects totaling nearly $1 million in seven nations *(CIMMYT Review, 1974,* p. 96). Comments on IRRI'S first decade of cooperative programs are provided in the following papers in *Rice, Science, and Man (op. cit.)*: A. Collin McClung, "IRRI's Role in Institutional Cooperation in Asia," pp. 19-40, and D. L. Umali, "Rice Improvement Through International Cooperation," pp. 81-97.

[20]These and many other such projects are outlined in *Summary of Ongoing Research and Technical Assistance Projects in Agriculture*, USAID, Bureau for Technical Assistance, June 1974, pp. 15-76.

III. RELATING RESEARCH RESULTS AND PRODUCTION CHANGES

It is a long way from the international agricultural research institute to the farmer's field. Relating the activities of the institute to actual changes in crop production requires an understanding of (1) the potential effects of research and (2) the reasons for the gap between potential and reality. To judge the results of international research in terms of farmers' yields is to judge many other aspects of the rural economy as well. It is a severe test.

3. The product of research: high-yielding varieties of rice in India.

Potential Effects of Research

The major product of the international institutes is new technology. New technology, in turn, brings about changes in the production process for the commodity involved. In terms of direct quantitative effects, (1) output is expanded at the same overall cost, or (2) the same output is produced at lower cost, or (3) some combination of these two results. Direct effects may also be accompanied by indirect effects.

Direct Effects of the HYV's

High-yielding varieties (HYV's) of wheat and rice are best known for their effect on the quantity of output. In addition, they may also influence the quality of the product.

Quantitative effect. HYV's usually bring about increased output per unit of land. While yields are increased, so are total costs per unit of land, because a package of associated inputs is needed. However, if HYV's are properly sited and used, returns per unit of product are usually increased.[1] This increased profitability is, of course, largely responsible for their widespread adoption.

Yield potential is increased largely because of the semi-dwarf characteristics of the varieties. This characteristic means that, compared to traditional varieties, additional fertilizer applications are more apt to result in increased grain development than in vegetative growth. The short, stiff straw also means that the varieties are less likely to lodge (fall over).

Although HYV's, given the proper package of inputs, usually have a clear yield advantage over traditional varieties, it is difficult to precisely measure the difference. The improvement is not the same for wheat and rice. And advantages vary widely within each crop, depending on the degree to which the recommended level of inputs is used, the quality of the land base, and a host of other factors.

In the late 1960's, multiples of two or three times the traditional yield were claimed for the HYV's. These were largely measures of *potential* taken from experiment station trials or supervised demonstration plots. In itself, this increased potential could be considered one possible measure of the fruits of international research. Actual farm yields, however, have been lower. Some of the reasons for this difference will be outlined later in this chapter.

The yield effect has taken two different patterns in the breeding programs for wheat and rice.[2] Semi-dwarf wheat varieties were not the first stage in the Mexican wheat breeding program; they came as a second stage and began to be released in the early 1960's. By contrast, the semi-dwarf characteristics were part of the IRRI rice breeding program from the outset. As a result, the yield potential of the newer Mexican wheat varieties, which incorporate the dwarfing characteristic, is greater than for the earlier improved varieties (see table 2). By contrast, the maximum yield potential of the IRRI varieties has not increased greatly since the introduction of IR-8.

Table 2—Yield potentials of wheat varieties bred by CIMMYT or predecessors and released by Mexico, selected years 1950-73

Year of cross	Variety name and year of Mexican release	Yield potential[1]	Plant height
		Tons/ha	*Cm*
1945	Yaqui 50	3.50	110
1958	Nainari 60	4.00	110
1956	Pitic 62	5.37	100
1956	Penjamo 62	5.87	100
1957	Sonora 64	5.58	85
1958	Lerma Rojo 64	6.00	100
1962	INIA 66	5.63	100
1957	Siete Cerros (66)	7.00	100
1966	Yecora 70	7.00	75
1966	Cajeme 71	7.00	75
1968	Tanori 71	7.00	90
1969	Jupateco 73	8.00	95

[1] Measured at experiment stations in Mexico. Irrigated and essentially disease free. Does not reflect international trials nor trials on private farmers' fields.

Source: *CIMMYT Review 1974*, p. 5. (The source table also provides disease ratings in Mexico as of 1973.)

These different patterns were in part related to disease problems. Rust (a mold-like fungus) was the major problem for wheat. Development of resistant varieties was considered the only answer, and Borlaug took up this work in 1945. By 1949, four new varieties were developed which were soon widely planted. A continuous battle is needed, however, as new strains of rust persistently appear.[3] In 1974, CIMMYT reported that while the wheat varieties which moved out of Mexico in the 1960's showed good resistance,

> . . .resistance to some of the rusts is now breaking down. New varieties with different genetic resistance are urgently needed. It appears that 10 years may be the longest period that a variety can withstand the constantly changing attack of the three rusts.[4]

Disease was not such an important factor in the early IRRI activities, but it soon became a serious concern. Other factors receiving major attention include insect resistance and tolerance to stress factors such as drought, cold, deep water, and soil problems.

In addition to looking for increased yield *potential*, the institutes are placing considerable emphasis on achieving yield *stability*. Resistance to insects and disease and tolerance to stress factors play a major role in reducing year-to-year fluctuations in production. In pursuing yield stability, CIMMYT is making a number of crosses between spring and winter wheats and with other cereals. IRRI has established a Genetic Evaluation and Utilization Program. As a result of the search for yield stability, the potential geographic area of varietal use may be broadened.

Some of these research efforts will produce higher average farm yields, and other research will be needed just to maintain higher yields in the face of ever-changing insect and disease attacks. Maintenance research, while absolutely necessary, may not show up well in conventional measures of productivity.[5] Since maintenance research may become increasingly important as agriculture becomes more complex,[6] it is vital that further attention be given to its measurement.

Qualitative effects. The new varieties differ qualitatively from traditional varieties in two main ways: consumer acceptance and nutrient composition. Some of the early institute wheat and rice varieties achieved only limited acceptance in certain areas because of color, appearance, or taste differences. The result was a lower price. Most of these problems have been taken care of in subsequent breeding programs, though traditional varieties still may be preferred in some places.

4. A training program for wheat specialists from developing nations at the International Maize and Wheat Improvement Center (CIMMYT).

The question of relative nutrient quality is more difficult to assess. It depends on an involved interplay of genetic makeup, quantity and timing of nitrogen applications, and environmental factors. On balance there may not be much of a difference between the HYV's and the traditional varieties.[7] Still, an attempt is being made to breed in higher protein levels or quality. This is particularly the case with rice.[8] The challenge is to find varieties which have both higher yields and higher nutrient levels.

Indirect Effects of the HYV's

The indirect effects of the HYV's, like the direct effects, may have important quantitative and qualitative dimensions. Both are often overlooked.

One of the major biological features of the HYV's, especially rice, is their photoperiod insensitivity, which often shortens the time needed to reach maturity and provides greater flexibility in planting dates.[9] This helps make it possible to grow an extra crop a year in some regions. Several rice-eating nations in southeast Asia have recently requested CIMMYT's help in introducing a wheat crop during the winter season.[10] And Pakistan is studying the possibility of growing two crops of wheat a year.[11] For these reasons, multiple cropping usually increases in green revolution areas; in fact Castillo notes that in Asia adoption of the modern varieties "is almost synonymous with the adoption of multiple cropping." In some cases where their yields were not superior to local varieties, "they were adopted nevertheless because of the shorter growing period."[12] Perhaps, in the long run, this indirect effect on output will be as important as or more important than the direct influence on yield.[13]

A second indirect effect is that higher yields may free resources for other uses. This was recently reported to be the case in Uttar Pradesh in India:

> The coming of the new technology has freed the small farmer from the less profitable cropping patterns on which he could always depend to provide minimum quantities of such staples as wheat and animal fodder for home consumption. If he grows high-yielding varieties, the small farmer can supply his home consumption needs and still have land remaining to grow high-yielding cereals for market or other high-profit crops like sugarcane.[14]

To take these and other effects into account, we should increasingly turn our attention from yields *per crop* to yields *per unit of land per year*. This will be particularly true as more work is devoted to developing improved farming systems.

* * *

The research on wheat and rice can have many economic and social effects beyond production. But measurement of the effect of research on output—detailed in later sections of this report—is a necessary and often missing link in the chain of analysis.

The Gap Between Potential and Reality

High-yield technology developed at the research level represents only potential for yield improvements. The technology must be transformed into reality in actual farmers' fields in the LDC's. Many factors outside the control of the experiment station intervene. Biological and economic constraints, as well as some traditional farming methods, can keep HYV's from being used optimally.

Nature of the Institute Product

The new varieties are generally high yielding only if accompanied by a package of inputs. The most important factors are fertilizer and improved management, but water and control of insects and diseases may also be vital. Of these, the international center provides only the seed and, in some cases, a set of recommendations. The other inputs have to be provided by the farmer at the local level. Many forces well beyond the farmers' control can affect the availability of some of these inputs, as has recently been vividly shown in the case of fertilizer. And other factors influence the farmers' willingness to actually use the inputs.

In many cases, the variety provided by the institute is only raw material which needs to be more fully refined for local use by national research programs. It is instructive that CIMMYT does not release varieties as such; rather:

> CIMMYT distributes germ plasm to national programs, and the governments. . .are free to release them as varieties under local names or they may use CIMMYT germ plasm in their own breeding programs. Either way, the national programs take responsibility for what is selected and released.[15]

Similarly, IRRI varieties have been reissued under other names and/or extensively crossed with local varieties in national programs.[16]

Another complicating factor in measuring research efforts is that some varieties which are included in the HYV category were developed in national programs either before the centers were established or independently of them. In fact, the IRRI and CIMMYT varieties are not wholly new varieties; in most cases, they build on generations of breeding efforts which have gone on before at the national and regional levels.[17] For these reasons, the new wheats and rices should be viewed as joint products of national and international research efforts. This, in turn, makes it most difficult to completely isolate the contributions of the institutes.[18]

Constraints on Realizing Potential

The HYV yield potential, determined on experiment stations, is often several times as high as that obtained in practice. In the Philippines, for instance, the potential rice yield is in the neighborhood of 8 metric tons per hectare (mt/ha), whereas actual overall yields (traditional and HYV) are slightly less than 2 tons.[19]

5. A farm demonstration trial in Southeast Asia. Short-stemmed high-yielding variety of IR-8 rice is at left; longer stemmed traditional variety is at right.

What accounts for such differences? First, the HYV's are not planted on all of the cropland. In Asia in 1972/73, the HYV's accounted for about 35 percent of the total wheat area and 20 percent of the total rice area. In a few nations the proportions were relatively high: for wheat the HYV proportion was 55.9 percent in Pakistan, and 51.5 percent in India; for rice the HYV proportion was 56.3 percent in the Philippines and 43.4 percent in Pakistan.[20] Data on trends are provided in figures 1 and 2.

Second, even with local breeding efforts, there are biological limits on the proportion of crop area suitable for the HYV's. For instance, much of the wheat area in Turkey is suited only for winter wheats, whereas the Mexican HYV's are spring wheats. Within an area planted to HYV's, numerous other biological problems

Proportion of total area planted to high-yielding varieties

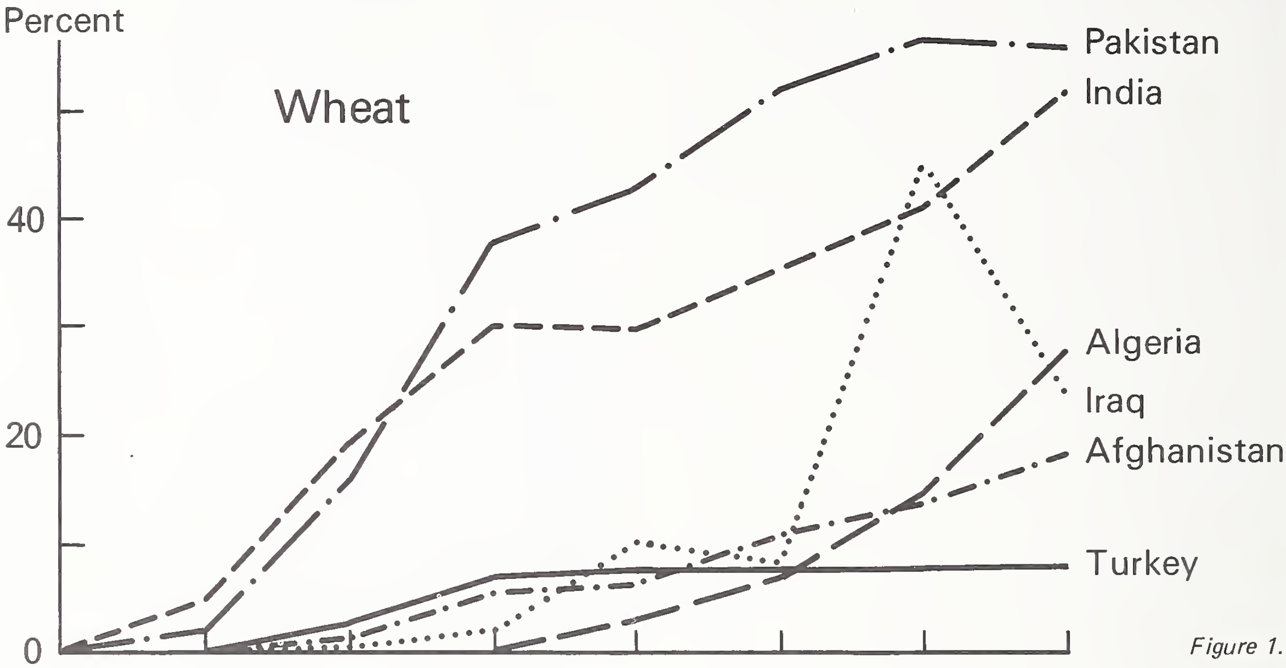

Figure 1.

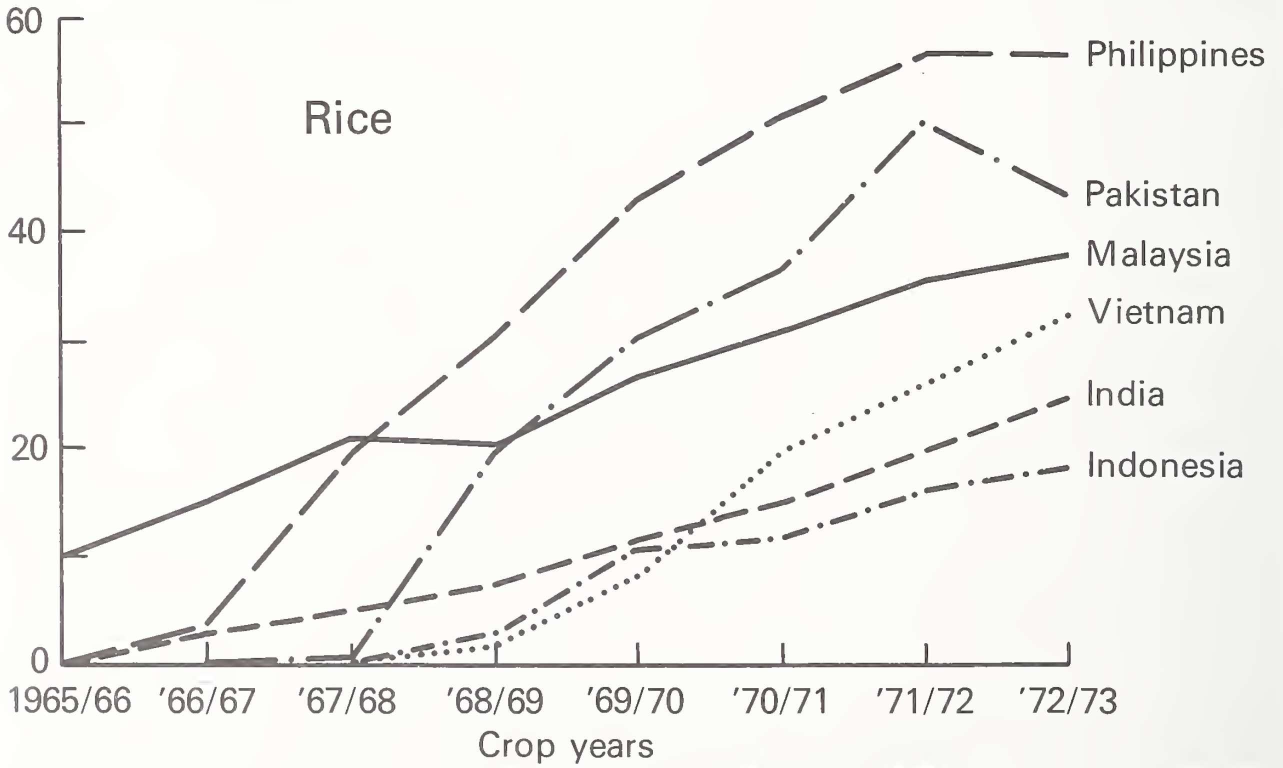

Figure 2.

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restrain output. A breakdown of the constraints reported in one small sample rice survey in the Philippines in 1972/73 suggests the variety of possible limitations that face the farmer:[21]

Limiting factor	Season	
	Dry	Wet
	Percent	
Insects and diseases	35	70
Water	26	--
Nitrogen	21	6
Weeds	9	18
Seedling	9	6

Some other factors restraining adoption may be classified as institutional/economic and risk/uncertainty.[22]

But even allowing for these factors, HYV yields are often not as high as might be expected. Part of this is because many farmers do not follow the recommended practices of levels of input use. The same Philippine survey noted above suggests the difference in rice yields due to farmers' practices:[23]

Practices	Yields	
	Dry season	Wet season
	Mt/ha	
Recommended	7.3	5.0
Farmers	3.9	3.3
Difference	3.4	1.7

A number of other studies have shown that many farmers either do not use recommended practices, or do not use them at recommended levels.[24] There are many reasons for this less than complete usage; in some cases continuation of traditional practices represents a rational allocation of resources under the financial, price, and other conditions at the farm level. In measuring increased yield and production at the national level, it is impossible to know for sure to what extent the recommended inputs have actually been used.

Hence the gap between potential and reality may be partly reduced by greater use of improved practices. And some of the biological factors can be at least partly corrected in time through research programs by developing, for example, greater insect and disease resistance. But there are technical and economic limits as to how far this process will go: there will always be some gap between potential and reality.

* * *

Thus, there are many other factors beyond the varieties themselves involved in the realization of higher yields at the farm level. To measure the productivity of the international institutes themselves on the basis of productivity at the farm level necessarily involves the measurement of many other factors as well—ranging from the effectiveness of the national research agency, to the weather, to the price of fertilizer.

References And Notes

[1] A recent example is Sidhu's study of wheat in the Punjab of India, which revealed that unit costs of production with the new varieties declined about 16 percent (Surjit Sidhu, "Economics of Technical Change in Wheat Production in the Indian Punjab," *American Journal of Agricultural Economics*, May 1974, pp. 217-226). On the profitability of HYV rice in six Asian nations, see Randolph Barker, "Changes in Rice Farming in Selected Areas of Asia: Some Preliminary Observations," IRRI, February 15, 1973, p. 7.

[2] For further details on the matters discussed here, see Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, U.S. Department of Agriculture, FAER No. 95, July 1974, pp. 9-20.

[3] See E. C. Stakman, Richard Bradfield, and P. C. Mangelsdorf, *Campaigns Against Hunger*, Belknap Press of Harvard University Press, Cambridge, 1967, pp. 74-88.

[4] *CIMMYT Review, 1974*, p. 7. The three types are stem rust, leaf rust, and stripe rust.

[5] For more detailed discussion of maintenance research in the U.S. context, see Willis L. Peterson and Joseph C. Fitzharris, "The Organization and Productivity of the Federal-State Research System in the United States," November 7, 1974, pp. 32-33, 37, 40 (RC).

[6] This point was suggested by Dr. Yoav Kislev, RC, January 26, 1975.

[7] Dana G. Dalrymple, "The Green Revolution and Protein Levels in Grain," U.S. Department of Agriculture, Economic Research Service, Foreign Development Division, unpublished manuscript, May 5, 1972, 12 pp.

[8] See, for example, *IRRI Research Highlights for 1973*, pp. 22-24.

[9] This matter is discussed in greater detail in Dalrymple, *op. cit.* (1974), p. 5.

[10] *CIMMYT Review, 1974*, p. 5.

[11] "Pakistan Aims for Two Wheat Crops Yearly," *Journal of Commerce*, December 26, 1974.

[12] Gelia T. Castillo, "Diversity in Unity: The Social Components of Changes in Rice Farming in Asian

Villages," IRRI, 1974, p. 2 (to be included in a forthcoming IRRI report).

[13] See Dana G. Dalrymple, *Survey of Multiple Cropping in Less Developed Nations* U.S. Department of Agriculture, FAER No. 91, October 1971, 108 pp.

[14] Ian R. Wills, "Projections of Effects of Modern Inputs on Agricultural Income and Employment in a Community Development Block, Uttar Pradesh, India," *American Journal of Agricultural Economics*, August 1972, pp. 457-458.

[15] *CIMMYT Review, 1974*, p. 7.

[16] See Dalrymple, *op. cit.*, (1974), pp. 17-21.

[17] See: Robert Evenson, "Consequences of the Green Revolution," Yale University, Department of Economics, July 1974, p. 387; Dalrymple, *op. cit.* (1974), pp. 9-20.

[18] Hence it is difficult to attempt, as Evenson has, to sort the HYV's, into three groups: (a) institute bred, (b) joint institute-national, and (c) other independent (Robert Evenson, "Comparative Evidence Returns to Investment in National and International Research Institutions," November 1974, pp. 21, 21a, RC). Furthermore, the HYV data for many countries are not sufficiently disaggregated by individual variety to make such a breakdown possible.

[19] *IRRI Research Highlights for 1973*, p. 46.

[20] Dalrymple, *op. cit.* (1974), pp. 71, 72.

[21] *IRRI Research Highlights for 1973*, p. 45. The data may overstate the importance of insects and diseases in the Philippines as a whole (letter from Robert W. Herdt, agricultural economist, IRRI, September 30, 1974).

[22] William Jones and I have reviewed these categories in greater detail in our unpublished paper on "Evaluating the 'Green Revolution'," USAID, Bureau of Program Policy and Coordination, processed draft, June 18, 1973, pp. 33-37. (Jones is with the World Bank.)

[23] *IRRI Research Highlights for 1973*, p. 45.

[24] A summary of some of these studies and factors is provided in Dalrymple and Jones, *op. cit.*, pp. 37-39, and Dana G. Dalrymple, "The Green Revolution: Past and Prospects," USAID, Bureau for Program Policy and Coordination, processed draft, July 22, 1974, pp. 13-16, 45-47.

IV. CHANGES IN AREA AND YIELD

Any change in crop production is a function of changes in area and yield. Improvements in technology are reflected, for the most part, in increased yield. New technologies are less often needed for expansion of area. Thus, in initially evaluating the effect of the HYV's on production, it is useful to determine the relative importance of area and yield changes.

Increased yields may be caused by many factors. Technology is only one factor; and the HYV's are only one form of technology. Still, we can gain an impression of the importance of HYV's by (1) comparing changes in HYV adoption and changes in production, and (2) examining relative yield levels of the HYV's and the traditional varieties. Comparative yields also provide the basis for a more sophisticated analysis of the effect of the HYV's on production, which will be made in the next chapter.

The Data Base

Data on area planted to HYV wheat and rice in developing nations go back to 1965/66, the first year the varieties produced by the research institutes began to be used internationally to any degree. The currently available data extend through 1972/73. It is often not possible to separate the institute varieties in direct use from their progeny and from other improved varieties, so they are all generally lumped together.

HYV data for non-Communist LDC's are broken down by country for 1972/73 in table 3 and are depicted in summary form for the 1965/66 to 1972/73 period in figure 3. Area devoted to the HYV's has expanded sharply, but it is still largely concentrated in Asia, with some HYV wheat in North Africa and some HYV rice in Latin America. Comparable data are not yet available for Communist nations.[1]

Total area planted to all types of rice can be obtained for these countries from data compiled by the Foreign Agricultural Service of the U.S. Department of Agriculture or by the Food and Agriculture Organization of the United Nations.

Table 3--Estimated area planted to high-yielding varieties, wheat and rice, less developed countries, 1972/73[1]

Crop/Country	Area	
	Hectares	*Acres*
Wheat		
Asia		
India	10,236,800	22,295,200
Pakistan	3,338,800	8,250,000
Turkey[2]	650,000	1,606,200
Iraq	457,000	1,129,000
Afghanistan	450,000	1,112,000
Iran	298,000	736,400
Syria	180,000	444,800
Nepal	170,300	420,700
Bangladesh	21,450	53,000
Lebanon	20,000	49,400
Jordan	150	380
Subtotal	15,822,500	39,097,400
Africa		
Algeria	600,000	1,482,600
Morocco	294,000	726,500
Tunisia	99.000	244,600
Subtotal	993,000	2,453,700
Total	16,815,500	41,551,100
Rice		
Asia		
India	8,639,100	21,347,200
Philippines[3]	1,752,000	4,329,200
Indonesia	1,521,000	3,758,000
Bangladesh	1,069,600	2,643,000
Vietnam (South)	835,000	2,063,300
Pakistan	643,500	1,590,000
Thailand	350,000	865,000
Malaysia	217,300	537,000
Burma	199,200	492,200
Korea (South	187,000	462,000
Nepal	177,300	438,000
Laos	50,000	123,600
Sri Lanka	17,600	43,500
Subtotal	15,658,600	38,692,000
Latin America		
Subtotal	429,600	1,061,400
Total	16,088,200	39,753,400

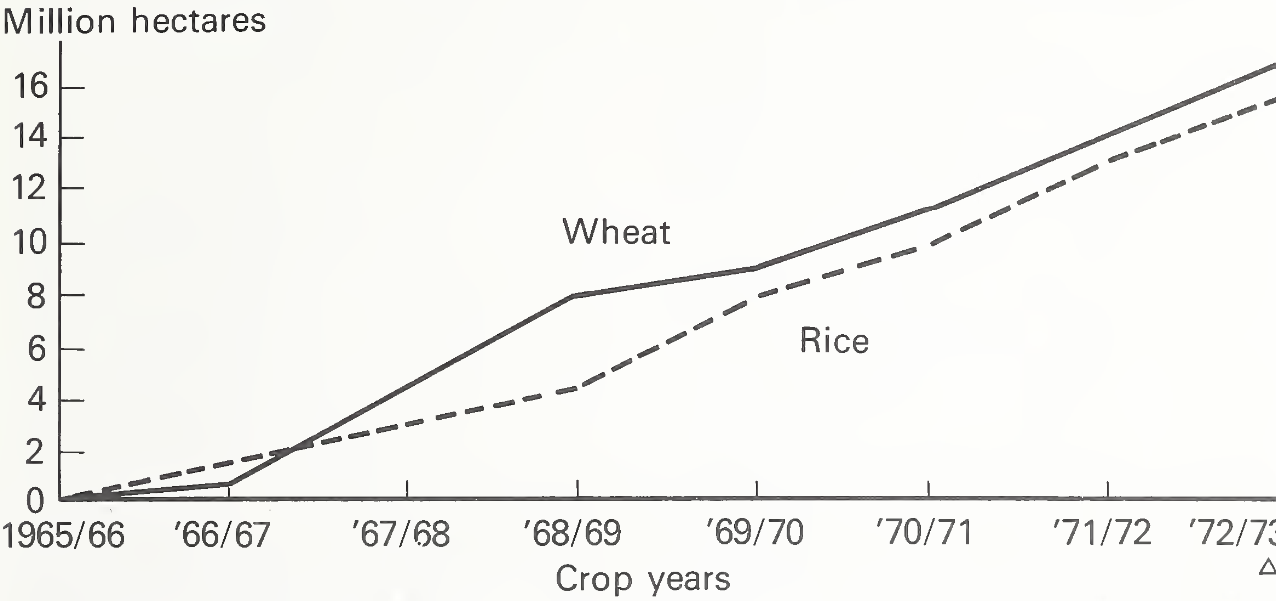
[1] Excludes Communist nations. Also excludes HYV wheat in Mexico and Guatemala and HYV rice in Taiwan. [2] 1971/72 estimate. [3] Unofficial estimate.

Source: Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations,* U.S. Department of Agriculture, Economic Research Service, FAER No. 95, July 1974, pp. 69, 70.

Deducting HYV area from the total area indicates, of course, area planted to regular varieties.

6. Opportunities for area expansion are limited in many regions of Asia such as this terraced rice paddy zone in the Philippines. Increased production must come from increased yields.

Estimated high-yielding wheat and rice area, Asia and North Africa (excluding Communist nations)



△*Preliminary.* *Figure 3.*

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For all countries listed in table 3, data can be found on total wheat or rice output. If the area planted to wheat and to rice is known, it is obviously possible to calculate the average yield for all varieties. However, calculation of relative yields of the HYV's is more difficult. In a few cases, the production and yield of HYV's is reported separately. But more often HYV yields have to be pieced together from a variety of sources.

Effect of Changes in Area and Yield

In assessing the impact of HYV's, some observers merely look at trends in total wheat or rice production in a particular LDC. If no further steps are taken, this is not an adequate way of measuring impact because it does not take into account relative changes in area and yield.

Nature of Area and Yield Expansion

There is little information available about the effect of the HYV's on the total cropped area. Considering their biological requirements, it is unlikely that they have stimulated the clearing of much new land for their use. Rather, they have probably substituted for existing crops on the better land. The question then is whether they have substituted for a traditional variety of a like crop or have substituted for other crops. It appears that they generally substitute for like crops, but this is not always the case, especially on irrigated land.

Area trends in India from 1967/68 to 1973/74 reveal different patterns for wheat and rice. In the case of wheat, there was fairly significant expansion of the total area. On the other hand, total rice area expanded only slightly. This suggests that the expansion of HYV wheat involved some replacement of other crops, while the HYV rice area appears to have largely substituted for traditional varieties. Much of the new wheat area would otherwise have been left fallow or planted to chickpeas or other crops;[2] in the Punjab the crops replaced included barley, gram, and cotton.[3]

Relatively little analysis has been made of comparative yield data at the national level. The catch here is the word comparative: while we

7. Increased yields depend on many factors, including varieties, such as this IR-8 variety of rice being transplanted in Asia.

have data on yields where HYV's were planted and where traditional varieties are planted, we usually do not have a comparison of the resource base. HYV's are normally planted on the best land. But as they are more widely planted, presumably expanding into less suitable land, yields drop off. Yield trends are discussed in detail later in this section.

Differentiating Area and Yield Effects

The first step in differentiating the effects might be to calculate changes in area and yield for countries with significant HYV adoption over a given period of time. For our purposes, averages of two 4-year periods, 1960-63 and 1970-73, have been tabulated. The comparisons are conservative in that 1972 was generally a poor year. Countries selected were those where 12 percent or more of the area was planted to HYV's from 1970/71 to 1972/73. Two countries, Nepal and South Vietnam, were left out.[4]

Both area and yield were expanded in each country (see table 4). But in every case except Malaysia, the relative increase was greater for yield than for area. The increase in yield ranged from 1.5 times higher than the increase in area for Indian wheat and Indonesian rice, to 2 times for Pakistan wheat, to 3 times for Pakistan and Indian rice. In the Philippines, virtually all of the increase was in yield.

Given this data, it is possible to more formally assess the relative importance of area and yield expansion. This is done in table 5, utilizing a formula outlined in the footnote.[5] On this basis, yield increases accounted for a significant portion of the expansion in production in six of the seven cases cited, and were of

Table 4—Relative increases in production, area, and yield, wheat and rice, 1960-63 to 1970-73

Crop/Country	HYV proportion 1970/71 to 1972/73	Increase in 1970-73 average over 1960-63 average		
		Area	Yield	Production
		Percent		
Wheat				
Pakistan	52.3 to 55.9	+22.3	+45.2	+77.8
India	35.5 to 51.5	+38.2	+56.1	+115.7
Rice				
Philippines	50.3 to 56.3	+0.4	+33.9	+34.2
Pakistan	36.6 to 43.4	+22.8	+73.3	+112.9
Malaysia	30.9 to 38.0	+43.7	+16.5	+67.2
India	14.9 to 24.7	+4.6	+13.8	+19.3
Indonesia	[1] 11.2 to 18.0	+18.8	+29.1	+53.4

[1] Government programs only. Additional HYV area planted in private plots.

Table 5—Roles of area and yield in production expansion, 1960-63 to 1970-73

Crop/country	Proportion of production increase due to expansion in:	
	Area	Yield
	Percent	
Wheat		
Pakistan	35	65
India	42	58
Rice		
Philippines	1	99
Pakistan	27	73
Malaysia (W)	70	30
India	26	74
Indonesia	40	60

[1] Calculated according to the following formula:

$$1 = \frac{\log(1 + a)}{\log(1 + p)} + \frac{\log(1 + y)}{\log(1 + p)}$$

Where *a*, *y*, and *p* are the percentages reported in table 4 (but carried out several decimal places in some cases).

moderate importance in the seventh. Yield increases accounted for virtually all of the expansion in rice production in the Philippines, and from 50 to 74 percent in the other five cases. Malaysia was the only case where area expansion was more important and this may have been due to the addition of some major irrigation projects.

Thus, while both area and yield expansion were involved in production increases in seven cases (five countries) with substantial areas planted to HYV's, growth in yields appeared generally to be more important.

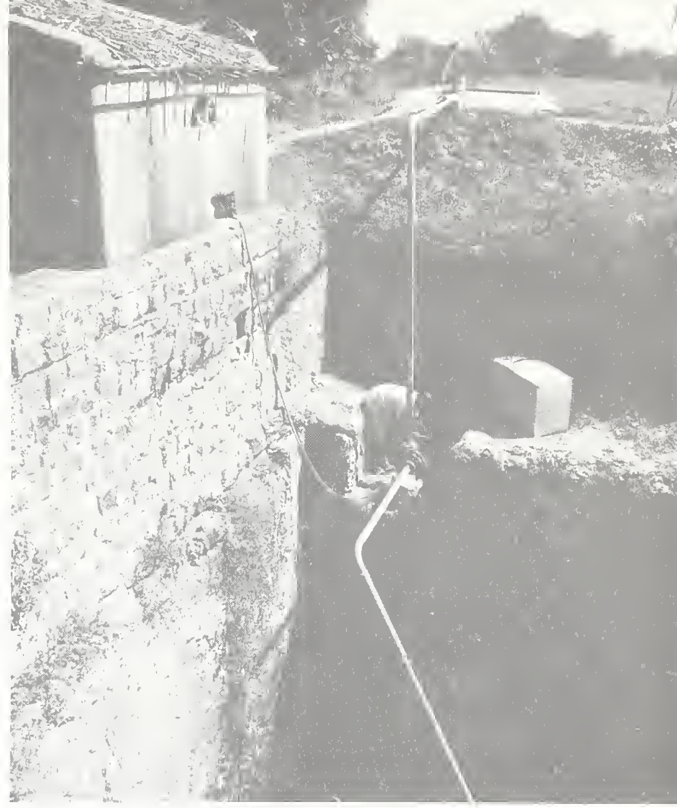
Annual Changes in Yield

It seems, then, that yield increases were an important factor in production increases in areas where HYV's were planted. What, then, did annual changes in overall yield patterns look like? How did they differ between HYV's and traditional varieties?

Overall Changes in Yield

Changes in national wheat and rice yields for the countries noted in the previous section are depicted in figures 4 and 5. The following trends are apparent:

Wheat (fig. 4). Yields were relatively steady in India and Pakistan through 1967, and then rose sharply in 1968.[6] Indian yields continued to rise through 1972, but dropped in 1973.



8. Improved cultural practices are required for improved varieties to achieve their yield potential. This tubewell unit is used to irrigate rice paddies in India.

Pakistan's yields moved up more slowly but continued to rise in 1973, exceeding Indian yields.

Rice (fig. 5).[7] Except in India, yields either remained about the same or rose only gradually through 1966, 1967, and 1968, and then increased fairly sharply. Pakistan and Indonesia showed the sharpest and most persistent gains. The Philippines moved up more moderately. India has shown only a gradual increase over the period. Yields dropped in three of the four countries in 1972, but increased in all of them in 1973.

Not surprisingly, these yield trends roughly coincide with the expansion of HYV area in each country as shown in figures 1 and 2 (except for the drop in Philippine rice yields in 1971 and 1972). The impact, however, seemed to be least for rice in India—probably because the HYV area represented only a small proportion of the total area, and because the HYV's used in India have not yet proved to be well suited to local monsoon conditions. Other factors besides the HYV package may well, of course, have had some influence.

Trends in wheat and rice yields

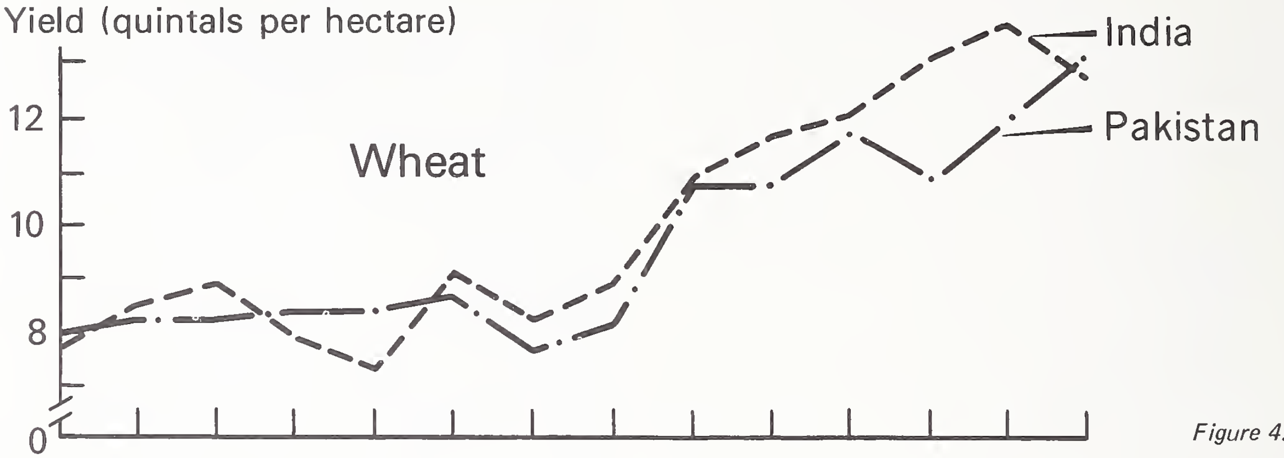
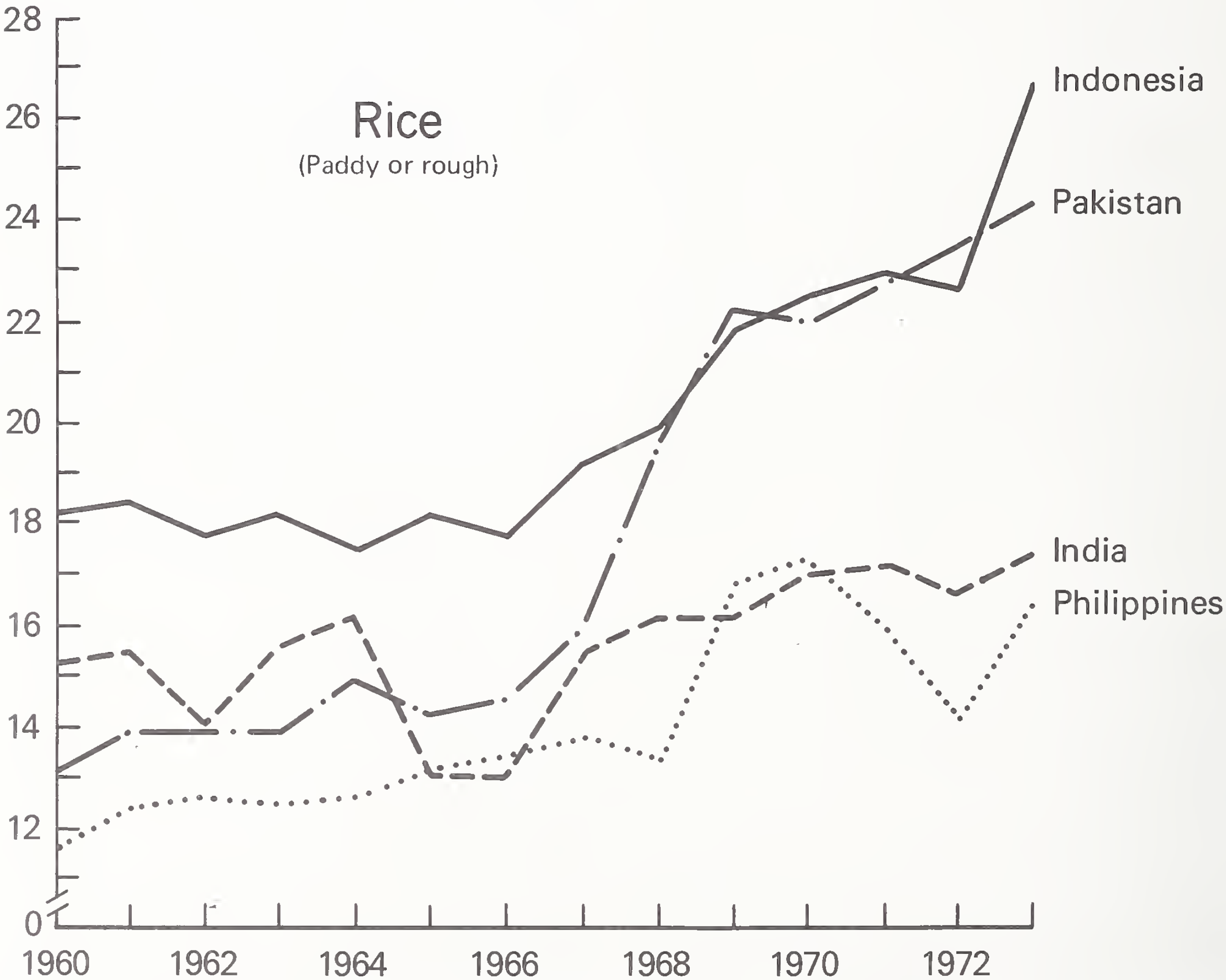


Figure 4.



Source: Foreign Agricultural Service, USDA.

Figure 5.

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Comparative Yield Levels

Some national data are available which give an idea of the yield levels of the HYV's compared to traditional varieties. These data can be misleading because, as noted earlier, the HYV's are usually planted on the better land. Even so, it may be of interest to review the official statistics and to compare them with other measures.

Official national statistics. A few such figures have been gathered. One USDA report summarized official national statistics for wheat from 1966 to 1970 for India, Pakistan, and Turkey.[8] It revealed that:

- —HYV yields were substantially above local varieties—from 1.77 to 3.70 times as great.
- —As area planted to HYV's expanded, their yield levels dropped, though not evenly.
- —As HYV area expanded, national yield levels increased.

These relationships would be expected. Because they produce higher yields, HYV's account for a larger proportion of total production than of total area. The difference in proportion, however, decreases as the average HYV yield level decreases over time.

Similar data are available for wheat and rice in India for the period from 1966/67 through 1973/74 (figs. 6 and 7).[9] They show the same general trends noted above, with a few variations. In India, yields for HYV's were from less than two to more than three times as high as traditional varieties. The wheat multiple was consistently higher than the rice multiple, though the difference narrowed later in the period. These ratios of HYV to traditional yields were fairly consistent through 1970/71, and then dropped:

Crop year	HYV yields in India as multiple of yields of traditional varieties: Wheat	Rice
1966/67	2.87	2.58
1967/68	3.70	2.18
1968/69	3.49	2.05
1969/70	3.68	2.26
1970/71	3.44	2.27
1971/72	2.50	2.03
1972/73	2.35	1.76
1973/74 (prelim.)	2.59	1.71

HYV wheat yields in India held relatively steady through 1970/71 (when 35.5 percent of the total wheat area was planted to them), and then dropped fairly sharply from 1971/72 on (fig. 6). Yields of traditional varieties at first dropped slightly and then rose in 1971/72. Yields for both HYV wheats and traditional varieties dropped in 1972/73 and 1973/74, with traditional varieties dropping relatively more than HYV's in 1973/74:

1973/74 yields as proportion of	HYV	Traditional
	Percent	
1972/73	92.5	84.2
1971/72	75.3	72.8

During 1972/73 and 1973/74, HYV and traditional wheat varieties seem to have been hit by the same factors. One is the diminishing availability of land which can be brought into cultivation without further increases in irrigated area.[10] In 1973/74, cool, dry weather also reduced yields.

Like the HYV wheats, yields for the HYV rices in India held fairly steady through 1970/71 (when they occupied 15 percent of the total rice area) and then dropped fairly sharply from 1971/72 to 1972/73 (fig. 7). The yield of traditional rice remained relatively level, while the yield of all varieties increased slightly through the period, except for a slight dip in 1972/73. As with wheat, both HYV's and the traditional varieties dropped in 1972/73, although in this case the HYV's dropped more. Widespread drought was a major factor, though perhaps not the only reason.

In the Philippines, official estimates for rice over the 1968-72 period suggest that HYV yields averaged from 1.30 to 1.35 times those of traditional varieties (including upland).[11]

Deflated comparative yields. If the land base were standardized, the comparative yield levels cited above would be somewhat lower. Several years ago I assumed—when pressed for a rough estimate—that the HYV package in irrigated areas might result in a relative yield ratio of 2.0 for wheat and 1.25 for rice.[12] The ratios would be lower in unirrigated areas.[13]

Unfortunately, it has not been possible to review enough studies to provide a good empirical check on these estimates. Two recent investigations, however, provide both larger and smaller multiples for rice, suggesting that the above figure may not be far off the mark as an average:

Trends in yields for traditional and high-yielding varieties, India

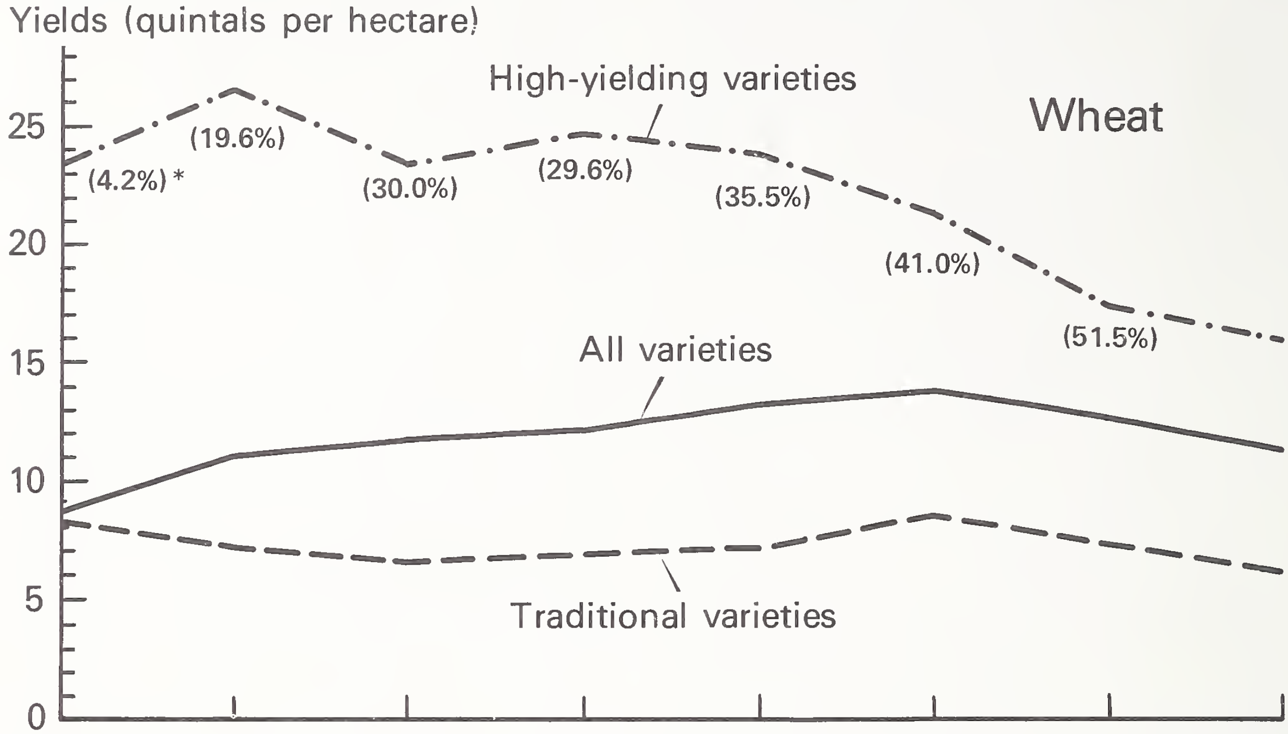
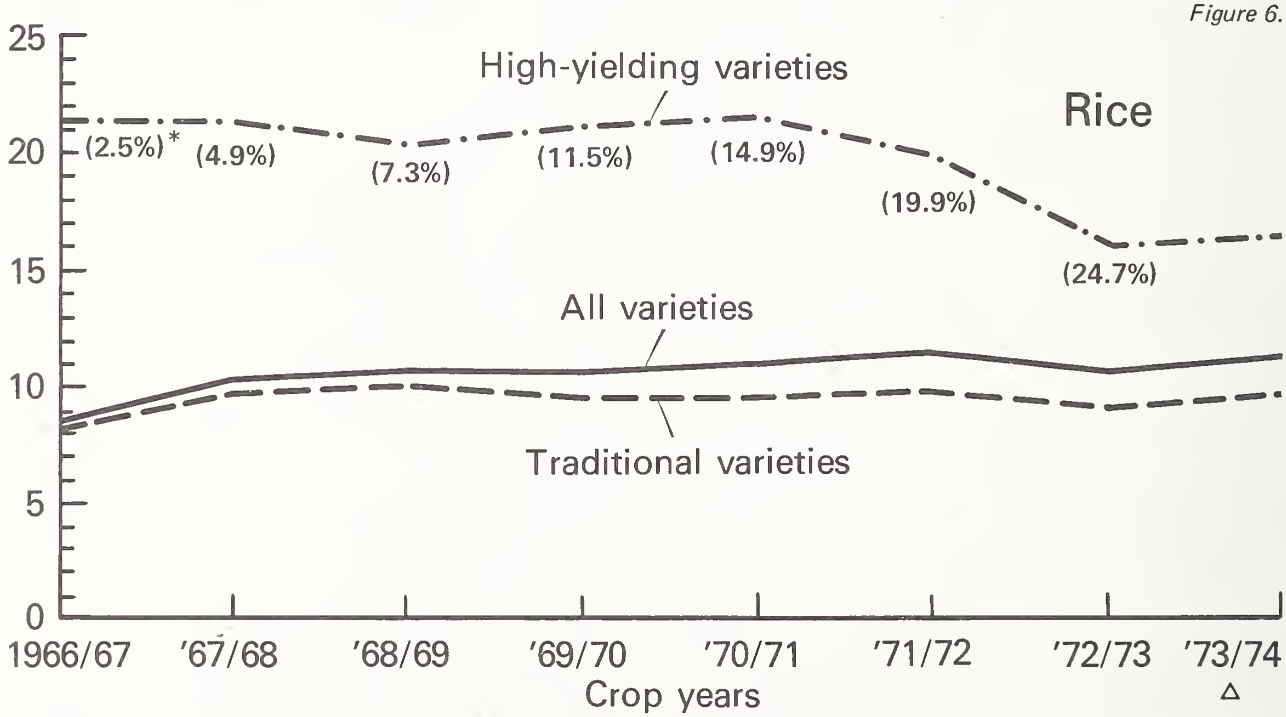


Figure 6.



△ *Preliminary.*

∗ *Proportion of total area planted to high-yielding varieties.*

Figure 7.

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9. An Indian farmer spraying field of high-yielding wheat.

—A study of rice production at the village level in six Asian nations in 1971-72 revealed that the overall multiple for both wet and dry seasons was somewhat higher: 1.32 to 1.33.[14]

—Somewhat lower ratios were obtained in the Philippines for the period from 1968 to 1972 when the national data reported previously were sorted out by type of land base. The HYV yield advantage was 1.14 on irrigated land and 1.03 on rainfed lowland.[15] Most HYV's are raised in irrigated areas. The multiple did not show any pronounced decline over the period; perhaps the arrival of improved varieties compensated for the possibility that lower quality land may have been planted to HYV's.

Numerous other data could undoubtedly be found;[16] the difficulty is to distill a meaningful average from them.

* * *

Obviously we need to know much more about actual yields at the farm level before we can make very precise evaluations of the contributions of the HYV's or the HYV package to increased yields. And we need to know much more about the influence that various inputs, the weather, and other factors have on production. The next chapter will examine these factors.

References And Notes

[1] For a summary of available information, see Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, U.S. Department of Agriculture, FAER No. 95, July 1974, Ch. VI, "Rice Improvement in Communist Nations," pp. 73-77.

[2] Based on review of statistics compiled by John Parker, Economic Research Service, U.S. Department of Agriculture. The specific sources of wheat area in 1970-71, compared to 1963-65, were calculated as follows:

	Percent
Land already in wheat, 1963-65	68.3
Land shifted out of gram (chickpeas)	14.7
Land from fallow or other crops	17.0
Land in wheat, 1970-71	100.0

(Carl C. Malone, "Indian Agriculture; Progress in Production and Equity" The Ford Foundation, New Delhi, October 1974, p. 99, table 20.)

[3] Surjit Sidhu, "Economics of Technical Change in Wheat Production in the Indian Punjab," *American Journal of Agricultural Economics*, May 1974, p. 221.

[4] Estimates of total wheat area, yield and production in Nepal vary. South Vietnam has been excluded because of the influence of the war.

[5] The formula was suggested by Bob Niehaus of the Economic Research Service and the calculations were carried out by him.

[6] Within District of the Punjab, the growth in wheat yields preceded widespread use of the current HYV's, beginning to climb sharply in 1963/64. This corresponded with a jump in nitrogenous and phosphatic fertilizer

use and in the number of tubewells installed (Arthur J. Dommen, "The Process of Production Change in a North Indian Village," University of Maryland, Department of Agricultural Economics, Ph.D. dissertation, October 1974, p. 199).

[7]Malaysia was not included on the chart simply because its yield levels averaged above the upper bound. It showed no particular trend from 1960 to 1967, but they moved up substantially in 1968 and 1969. More moderate increases were registered in 1971 and 1973. Changes in accounting and reporting systems may have influenced some of the Philippine data.

[8]Sheldon K. Tsu, *High-Yielding Varieties of Wheat in Developing Nations*, U.S. Department of Agriculture, ERS-Foreign 322, September 1971, 40 pp.

[9]Based on statistics compiled by John Parker, Economic Research Service, U.S. Department of Agriculture, May 20, 1974.

[10]Kenneth Murray, "India's Wheat Harvest to Fall Below Last Year's, Supply Tight," *Foreign Agriculture*, May 13, 1974, p. 3. Murray also suggests two other factors: farmer uncertainty concerning the Government's wheat policy (the grain trade was nationalized during 1973/74), and diversion of some wheat area to other crops which were not monopoly controlled.

[11]Mahar Mangahas and Aida R. Librero, "The High-Yield Varieties of Rice in the Philippines: A Perspective," University of the Philippines, School of Economics, Institute of Economic Development and Research, Discussion Paper No. 73-11, June 15, 1973, p. 23.

[12]These estimates were subsequently used by an economist at the World Bank in preparing a rough assessment of the increase in output resulting from the HYV's (*Agriculture: Sector Working Paper*, World Bank, June 1972, p. 8). In making this assumption I presumed that the HYV's would be raised on the better irrigated land.

[13]In the case of wheat, the countries cited have made extensive use of irrigation. A preliminary review of the data for dryland wheat production in North Africa and the Near East does not yet show a clear pattern of yield increase. This may be because levels of adoption are still relatively low, but may also reflect (1) the impact of lower water levels and of variations in rainfall, and (2) the fact that the traditional varieties in some of the North African nations really are improved varieties that were introduced over the 20th century and in some cases have characteristics and ancestry similar to the Mexican varieties. Further detail on the latter point is provided in Dalrymple, *op. cit.* (1974), pp. 9-15.

[14]Calculated from Teresa Anden and Randolph Barker, "Changes in Rice Farming in Selected Areas of Asia," IRRI, December 1, 1973, table 8.

[15]L. J. Atkinson and David Kunkel, "HYV in the Philippines: Progress of the Seed Fertilizer Revolution," U.S. Department of Agriculture, Economic Research Service, Foreign Development Division, unpublished manuscript, December 10, 1974, appendix table 1. Other computational variations are also presented in the appendix, and discussed in the text (pp. 5-7). (To be published as a Foreign Agricultural Economic Report.)

[16]It may be of historical interest to note that in Taiwan from 1922 to 1942 "on average, ponlai rice yields were 15 percent higher than those of native varieties" (Carolle Carr and Ramon H. Myers, "The Agricultural Transformation of Taiwan: The Case of Ponlai Rice, 1922-42," in *Technical Change in Asian Agriculture*, ed. by R. T. Shand, Australian National University Press, Canberra, 1973, p. 37).

V. MEASURING IMPACT ON PRODUCTION

The next step in analyzing the impact of the new technology is to evaluate its effect on production. The main problem in doing this is that a great many different factors influence changes in production. Furthermore, we do not know precisely what production would have been in the absence of new technology.

To measure production changes, most economists would use (1) a production function, or (2) an index number approach.[1] Each technique has its advantages and limitations. This chapter will briefly review both techniques in the context of wheat and rice production, then present a simplification of the index number technique. Finally, the findings of these two approaches are compared.

Production Function Analysis

A production function is a form of multiple correlation (or regression) analysis in which changes in production are treated as a function of variations in a number of input variables. The variables might include, as Evenson has suggested, (1) utilization of land, (2) fertilizer, (3) irrigation, (4) other agricultural inputs, and (5) some measure of the new technology introduction, such as the percent of the crop produced from the new varieties.[2]

Data Requirements

While a logical functional form can be fairly easily laid out, the problem is to obtain statistical data for each of the input variables. This can be accomplished at local or regional levels by farm surveys, but it is a very difficult task at the national level. About the only information readily available is the HYV area. Fertilizer is of critical importance, yet no LDC reports regular national data on the amount of fertilizer applied to individual crops such as wheat or rice, let alone to HYV's. All that is reported on an annual basis is the amount of fertilizer apparently consumed on all crops (these data are presented in FAO's annual *Fertilizer Review*). Some export or nonfood crops are large users of fertilizer. Insecticide and pesticide use is even less clear. Irrigation is not such an unknown, but it varies a great deal in quality and we have only a vague idea of the amount of irrigated land devoted to HYV's.[3]

Even if these data were available, we would have to take other variables into account. Perhaps the most difficult to measure is weather. While there have been sharp changes in weather since the mid-1960's, and 1972 was particularly bad, there are apparently no indexes which adequately measure the total yearly changes in weather. Perhaps over a long enough time period these changes would balance out, but the period at hand is only 8 years long. Some national data are available which make a start possible, such as the all-India rainfall indexes,[4] but they are only partial weather measures.

A more easily measured variable is the change in prices of both the product and the various inputs. Increased product prices and lower input prices would be expected to increase adoption of innovations. Such changes have taken place in the price of rice and of urea (see fig. 8). The cost of irrigation water depends on the source, but so does quality (in terms of when it is available): canal water is usually much cheaper than tubewell water, but the timing of application of tubewell water can be regulated much more closely.

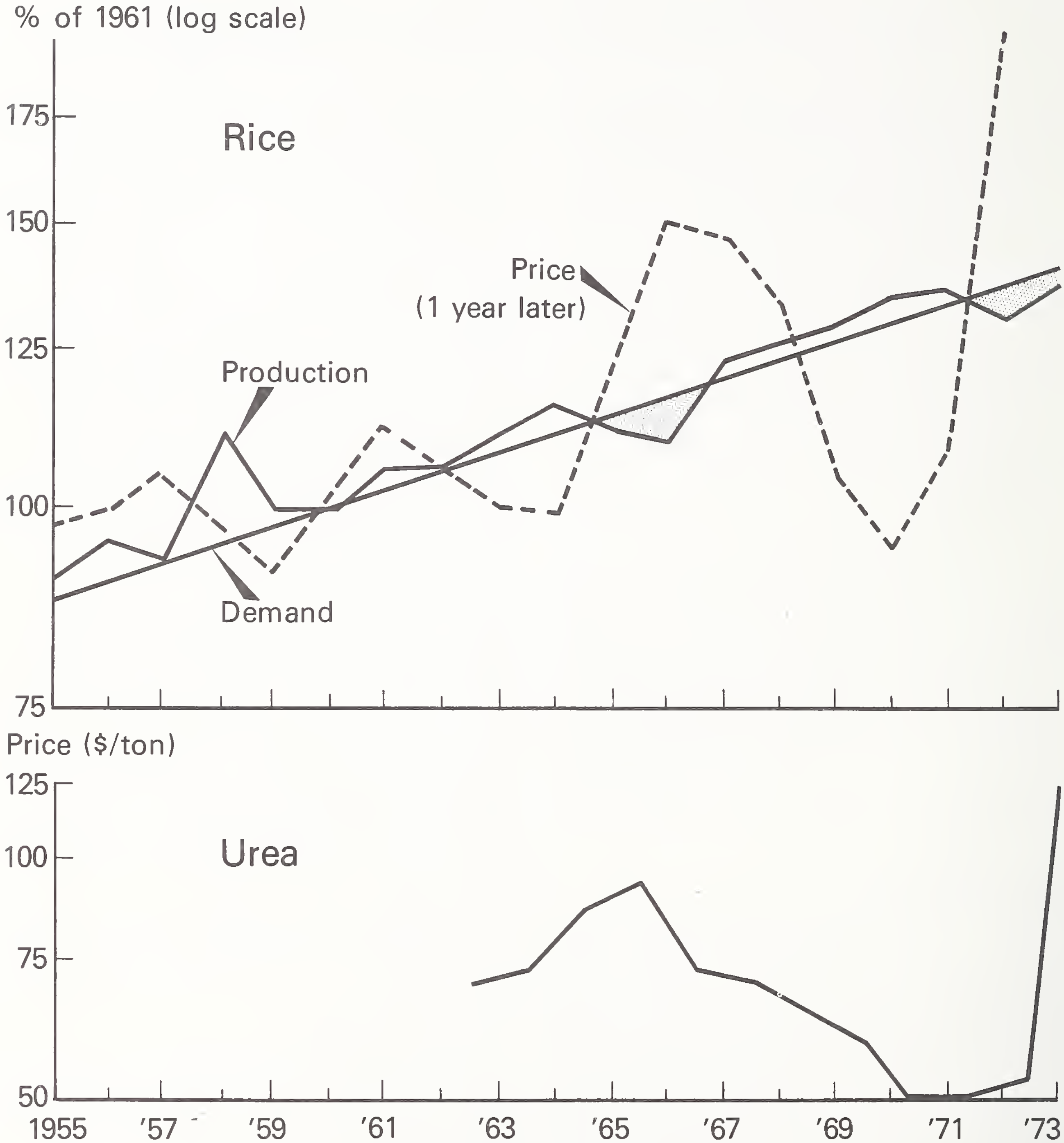
All of these factors, as well as others, should be considered in specifying a production function—but this is much easier said than done.

Two Recent Analyses

Despite these problems, many production function analyses have undoubtedly been conducted. Two recent studies on wheat and rice may be representative. One was done at a very aggregate level. The other was conducted at the regional level within a country. Both used Cobb-Douglas production functions.

Evenson study. Robert Evenson recently reported on a highly aggregated analysis for

World demand, production, and lagged price of rice and urea



Source: IRRI Research Highlights for 1973, p.8.

Figure 8.

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wheat and rice for Asia and the Middle East.[5] He first considered a country-by-country analysis, but because of data problems focused on a regional grouping, using one group of countries for wheat and another for rice. Fertilizer was measured in terms of total use on all crops, and the HYV areas were based on my earlier area compilations.[6]

The analysis was carried out in two steps. In the first stage, production was expressed as a function of crop area, total fertilizer use, and the proportion of crop area planted to HYV's. In total, these variables explained nearly all of the variation in wheat and rice production. Each variable was significant but crop area was the most important. It was surprising that such a crude measure of fertilizer use was significant, but not that overall crop area was more important than the HYV area, since the latter was of some magnitude only late in the period. In the second stage of his analysis, he introduced a number of other measures of research. The results with respect to the above variables were roughly similar.

As a result of the two-stage analysis, Evenson concluded that:

> . . .while the high-yielding varieties did contribute very significantly to increased production, they were by no means the sole source of productivity gains in LDC agriculture.[7]

Other important sources of productivity growth besides the HYV's and fertilizer were indigenous research findings and borrowed research discoveries. While two studies revealed (as suggested in chapter IV) that the superiority of the HYV's drops as their portion of the total area planted increases, a subsequent and more refined analysis indicated that this decline could be offset to a considerable degree by indigenous research which modifies the technology to local conditions.[8]

Evenson went on to calculate the increase in wheat and rice production in the countries studied and then converted this to value terms (table 6).[9] Even if the figures are only roughly accurate, they suggest that the increased production due to the use of the HYV's was substantial.

Sidhu study. Surjit Sidhu has recently reported the results of a study on wheat in the Punjab of India for the 4-year period from 1967/68 to 1970/71.[10] Production, again, was the dependent variable; the independent variables were cropland, capital services, fertilizer/manure, and labor. All independent variables proved to be significant except, in some cases, labor. When production functions were run for HYV and non-HYV farms in 1967/68, it was found that the new varieties used more of all inputs on a per unit of *land* basis; however, "a unit of *output* of new wheat consumes less of all inputs, including land, than old wheat. . ." and this "is of crucial importance as a source of growth."[11]

Table 6—Increase in production and value associated with the use of high-yielding varieties, Asia and Mideast

Crop year	Increase in: Production		Value	
	Wheat[1]	Rice[2]	Wheat[3]	Rice[4]
	Percent		*Million dollars*	
1965/66	.01	.01	0.4	1.3
1966/67	1.50	1.00	58.0	148.0
1967/68	10.90	3.30	436.0	463.0
1968/69	18.30	5.50	732.0	784.0
1969/70	19.30	9.60	772.0	1,365.0
1970/71	22.10	12.70	884.0	1,798.0
1971/72	24.00	16.50	960.0	2,329.0
1972/73	28.20	20.70	1,128.0	2,933.0

[1] 13 countries. [2] 12 countries. [3] Wheat priced at $75/mt. [4] Rice priced at $100/mt.

Source: Robert Evenson, "Consequences of the Green Revolution," Yale University, Dept. of Economics, unpublished manuscript, July 1974, p. 14, table 4. (Identical value data are reported in "Comparative Evidence on Returns to Investment in National and International Research Institutions," [November] 1974, p. 21a, table 6. RC)

For the year 1967/68, the percent "magnitude of the natural upward shift in the wheat production function resulting from the introduction of new wheat" was 22.85 percent.[12] In a subsequent paper, using a somewhat different formulation, Sidhu found an increase in efficiency of 44.79 percent.[13] These two figures form, he feels, the lower and upper limits of the actual change in productivity.[14]

For the other 3 years of one study, analyses were carried out for HYV's only.[15] The results suggested a downward shift in the production function after 1967/68. Sidhu thought that this drop may have been due to weather, deterioration in seed quality (due to mixing), and addition of marginally "inferior lands," but noted that "an assessment of their relative influences seems impossible." The downward shift in the production function, however, was

10. The final product—harvesting high-yielding rice in the Philippines.

to some extent reversed in 1970/71. Sidhu was not sure whether the downward movement "was a temporary phenomenon or is a long-run technological regression in the production of new wheats."[16]

If Sidhu is right in suggesting that declining seed quality may be due to mixing, and some other recent references from India suggest that he might be,[17] we have another complex and largely unmeasurable variable that should be considered. Forms of "technological regression," however, can be corrected to some extent in national research programs, as Evenson's analysis (cited above) has indicated.

* * *

Production functions, though they provide an analytically attractive approach, do have severe data problems unless they are based on farm surveys. And even if they are, there is the problem of extrapolating the results to the national or international level. Is there a way to get around these problems? The index number approach is one possibility.

Index Number Analysis

The result of a new technology is usually an increase in output for a given set of resources. Through use of the index number approach, it is possible to measure the magnitude of this increase and of its value to society. A number of economists have used this approach at the national level.[18] The index number technique can build on some of the results of production function analysis. While the index number approach does have some limitations, these can be partially avoided by tying this approach with production function analysis.

The General Formulation

In economic terms, the introduction of a new technology leads to a shift in the supply curve (graphically shown in fig. 9) Curve *St* represents the supply situation with traditional technology. Curve *Sn* represents the supply situation if the new technology is utilized. With the introduction of the new technology, the quantity of product is increased and the price is reduced.

Effects of a new technology in shifting the supply curve

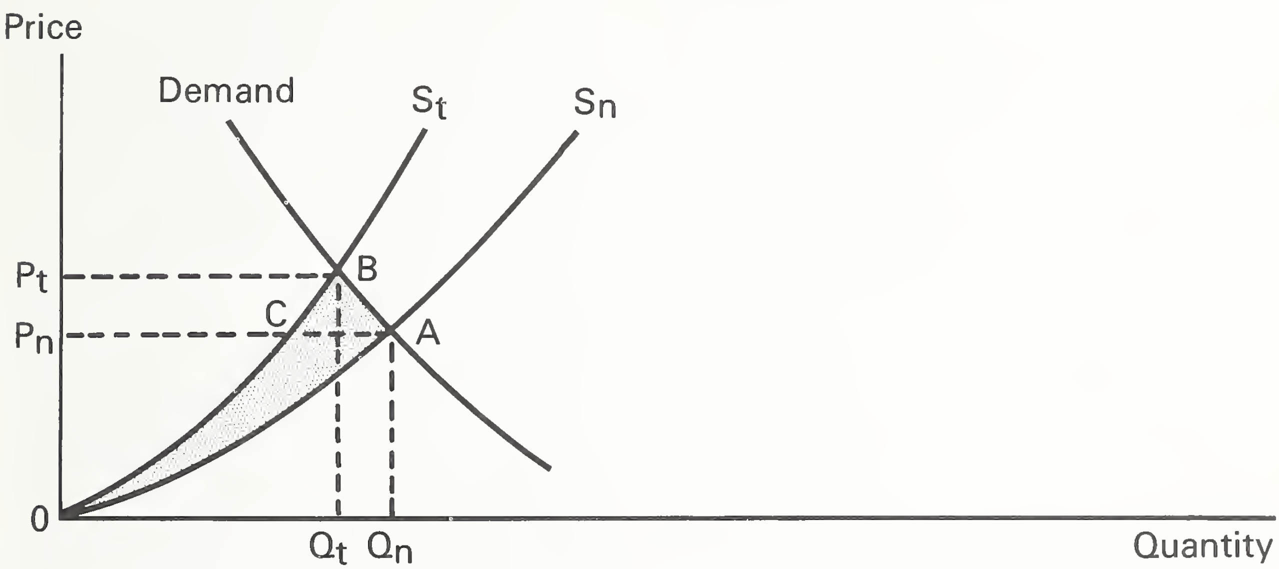

Figure 9.

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This change results in a gain to society, which is indicated by the shaded area, *OAB.*[19] Since only part of the farming area may utilize the new technology, the actual supply curve would lie somewhere between *Sn* and *St*.

Estimating techniques. The usual index number analysis involves a three-stage process, including estimation of (1) gross benefits, (2) research costs, and (3) rate of return over time. Obviously, a full-blown index number study could be rather involved and would demand much data. It also goes beyond the scope of this study, which is to evaluate effects on production. Therefore we will focus on step (1), the measurement of gross benefits.

Even the estimation of gross benefits, however, is a rather complex process. The major components and their functional form may be summarized as follows:[20]

$$B = PQK\ (1 + K/2\ E_D)\ (1\text{-}[(1\text{-}E_D)^2\ E_S/\ (E_D - E_S)]\ )$$

where:

B = gross benefits

P = price of the product

Q = quantity of the product

K = shift in supply curve due to research

E_D = elasticity of product demand

E_S = elasticity of product supply

The most difficult factor to measure, in turn, is K. This is because it is hard to separate out the many other factors which may influence productivity, but production function analysis can be very helpful in this process. E_D and E_S may also be difficult to determine over broad areas.

Possible simplifications. Is it possible, for introductory purposes, to get around some of the data problems by simplifying step (1)? A look at three previous studies provides some help with respect to K, E_D and E_S.

Several types of estimates of K have been utilized. In his classic study on hybrid corn, Griliches simply assumed, using some industry estimates, that yields were 15 percent higher than open-pollinated varieties (a shift which he identified as K).[21] A subsequent study by Ardito Barletta of the effects of crop research in Mexíco made use of three different estimates of K: (1) experiment station results (30 percent), (2) a weighted average from regression analysis (39 percent), and (3) a figure obtained by assigning all productivity increases to the new wheat and subtracting the additional costs.[22] Hertford and Ardito used the results of farm level experimental trials.[23] In terms of *effects*, measures which are close to the farm level would be most desirable; in terms of measuring *potential*, experiment station results might be most useful.[24]

How necessary is it that elasticity estimates, E_S and E_D, be included? When Griliches postulated various supply and demand elasticities, he found that "these elasticities have only a second-order effect, and hence different reasonable assumptions about them will affect the results very little."[25] In a concurrent investigation of the returns to research on a disease-resistant cotton in Brazil, Ayer and Schuh found, in calculating internal rates of return, that the results were changed only a little by different assumptions about the respective price and supply elasticities.[26] In reviewing these three papers, as well as Ardito Barletta's, the Statistics Division of the Ministry of Overseas Development in the United Kingdom summarized calculations which suggested that when the elasticity of demand is within the range of -0.5 to -1.85, changes in the elasticity of supply make little difference (less than 5 percent) in the amount of benefit.[27]

All told, then, these findings suggest that (1) it is possible to be flexible and pragmatic in obtaining estimates of K, and (2) that introductory analyses might leave out estimates of E_S and E_D. Clearly, more precise analyses should include the elasticities.

Contribution of the HYV Package

Considering data available for wheat and rice, and the possible simplifications suggested in the previous section, the gross contribution of the HYV package to production can be readily estimated by a sequence of a few simple formulas. Several different values for K, the shift due to research, will be assumed.

The formulation. The available and required data are described in the following algebraic notation:

Varieties	Area	Yield	Production
Traditional	A_t	Y_t	Q_t
HYV	A_{hyv}	Y_{hyv}	Q_{hyv}
All varieties	A_T	Y_T	Q_T

K is the equivalent of $\dfrac{Y_{hyv}}{Y_t}$. Five of the nine variables are known: A_t, A_{hyv}, A_T, Y_T, and Q_T. The variables that need to be calculated are: Y_t, Y_{hyv}, Q_t, and Q_{hyv}. Q_t and Q_{hyv} as used here, however, are not simply the production from each type of variety: rather Q_t is the quantity that would be produced if all of the area were planted to traditional varieties, and Q_{hyv} is the additional production due to the HYV package. Four different levels of K have been postulated: 1.25, 1.50, 1.75, and 2.0

The estimating process is composed of three steps, each of which utilizes a formula.

(1) Estimated yield of traditional varieties (Y_t)

$$Y_t = \frac{Q_T}{A_t + (A_{hyv} \cdot K)}$$

(2) Total production if total area planted to traditional varieties (Q_t)

$$Q_t = Y_t \cdot A_T$$

(3) Additional production due to HYV package (Q_{hyv})

$$Q_{hyv} = Q_T - Q_t$$

The derivation of formula (1) is

$$Q_T = (A_t \cdot Y_t) + (A_{hyv} \cdot Y_{hyv})$$

$$Q_T = (A_t \cdot Y_t) + (A_{hyv} \cdot (Y_t \cdot K))$$

$$Q_T = Y_t\,(A_t + A_{hyv} \cdot K)$$

$$Y_t = \frac{Q_T}{A_t + (A_{hyv} \cdot K)}$$

This is, as suggested, a fairly simple estimating process. It is also flexible: it can be used at any level for which data are available. The main

limitation is, as with the index number approach generally, the derivation and specification of *K*.

The assumptions. Although a range of assumptions on the value of *K* has been specified, which one appears to be most realistic? In the past, as noted previously, I have used a rough estimate of 1.25 for the HYV rice package and 2.00 for wheat in Asia. Data from several countries suggest that ratios for wheat range from 1.77 to 3.70 and for rice from 1.10 to 2.58. Sidhu's production function analysis indicates farm-level figures ranging from 1.23 to 1.45 for wheat in the Indian Punjab in 1967/68. Research by Hertford and Ardita in Colombia placed the yield advantage in 1971 as 1.46 for the improved wheat varieties and between 1.25 and 1.39 for rice.[28] Clearly there is a wide variation in the ratios.

One explanation for this range of estimates is that they may describe different things. The HYV *package* is purposely referred to throughout this report. The varieties *alone* may not have a significant effect on overall production because of the need for other elements of the package, particularly increased fertilization. On the other hand, without the improved variety, the full utility of the other inputs may not be realized. While some of these factors may be sorted out at the local level through the use of production function or regression analysis, this is much more difficult to do at the national or international level.[29]

Of the various *K* factors postulated, the most likely for the Asian region as a whole might be 1.25 for *rice* and 1.50 for *wheat*. The wheat figure is less than that used a few years ago, partly because of (1) the declines in HYV yields as they are planted more widely within nations (as shown in figures 6 and 7 for India), and (2) the fact that some of the newer wheat plantings are in the Near East, where water supplies may even be more limited than in South Asia.[30]

The outcome. When the index number approach is applied to wheat and rice in Asia[31] for the 1972/73 crop year, the calculations produce the results given in column 3 of table 7. (Column 2, the percentage increase, is simply calculated from some of the original data.) Obviously the results vary considerably, depending on which yield or K factor is utilized. If *K* factors of 1.25 for rice and 1.50 for wheat are selected as most realistic, the calculations suggest that in 1972/73 the HYV package added 8.7 million metric tons of wheat and 7.7 million metric tons of rice. In terms of the total crop, overall wheat output was increased by 18.3 percent and rice output increased by 4.9 percent.

These figures may be more meaningful when converted to value terms, though this is a hazardous step since it is difficult to select appropriate prices to use for a broad geographic area. If, to facilitate comparison, one applies the prices used by Evenson ($75/ton for wheat and $100/ton for rice), the gross value of the increased output in 1972/73 is striking: $656 million for wheat and $769 million for rice, or a total of $1,425 million.

These prices, however, may be on the high side. They are close to international levels[32] and do not reflect the effect of increased output on local prices.[33] If they are arbitrarily reduced by a third (to $50/ton for wheat and $67/ton for rice) to better reflect these factors, the results are still most impressive: an increase of $435 million for wheat and $513 million for rice, or a

Table 7—Estimated increase in wheat and rice production in Asia under different HYV yield assumptions, 1972/73 crop year[1]

Assumption	Increase in output					
HYV yield as multiple of traditional yield	Proportion		Quantity[2]		Value	
	Wheat	Rice	Wheat	Rice	Wheat[3]	Rice[4]
	Percent		*Million metric tons*		*Million dollars*	
1.25	9.1	4.9	4.2	7.7	314	769
1.50	18.3	9.8	8.7	13.8	656	1,379
1.75	27.4	14.7	11.8	18.4	881	1,841
2.00	36.6	19.6	14.4	23.5	1,080	2,354

[1] Excluding People's Republic of China, North Vietnam, Japan, and Israel. [2] Calculated according to formulas (1), (2), and (3) in text. [3] At $75/mt. [4] At $100/mt.

Sources of data used in calculations: HYV area data based on table 3. Other area, yield, and production data derived from statistics compiled by the Foreign Agricultural Service. Prices are the same as those used by Evenson (see table 6, footnotes 3 and 4).

11. Winnowing high-yield rice in Central India.

total gross value of about $950 million.[34] Overall, it seems fairly reasonable to suggest that the gross value of the HYV wheat and rice package in 1972/73 was about $1 billion for Asia alone.

Even though the overall output increases are not great in percentage terms, especially in the case of rice, the areas involved in non-Communist Asia alone are so vast that the total figures are inevitably significant. The monetary values would be even higher if North Vietnam, North Korea, Latin America, and Africa were included. However, if the additional cost of inputs were subtracted from the gross figures, they would of course be lowered.

Comparison of Results

How do the results obtained using index number analyses compare with those obtained by Evenson for 1972/73 using production function analysis (reported in table 6)? The statistical findings, using the same prices, may be summarized as follows:

Analytical method	Crop	Number of countries	Increase in total production	
			Percent	Gross value
				Million dollars
Production function	Wheat	13	28.2	1,128
	Rice	12	20.7	2,933
	Total			4,061
Index number	Wheat	Asia*	18.3	656
	Rice	Asia*	4.9	425
	Total			1,425

*Non-Communist

While the data cannot be precisely compared because of differences in countries and regions involved, it is clear that the index number figures are relatively conservative. This is a bit surprising; it would seem that Evenson's production function approach, which should more nearly isolate a pure variety effect, would give a lower figure than the index number approach, which reflects the varieties and the other components of the HYV package. The difference in the results could be narrowed considerably if I had assumed higher yield levels.[35]

Just as Evenson has presented estimates on production increase and value for the previous years (table 6), I could do the same. But since the yield ratio between HYV's and traditional varieties has changed over time and has generally declined, it might be appropriate to use different yield assumptions for past years. And perhaps the effect of some lower ratios (such as 1.20 for rice) should also be calculated.

The yield advantage may, of course, vary by season if there are widespread weather changes. It may be significantly reduced where, as has been the case recently, fertilizer supplies are scarce and prices high. On the other hand, lower yields may be offset by higher grain prices in calculating gross returns.

The index number procedure outlined here seems a promising initial measure of the effects of the HYV package. It is simple and flexible. It is reasonable in its data requirements. It can make use of production function analysis. It does not require any arcane skills (or computation equipment).

But these factors may also be its weakness. It is only an introductory process. To be at least reasonably accurate, it requires a more systematic and thorough evaluation of the yield ratios between the HYV package and the traditional

practices than we have at present for many areas. And even then, as is typical of the index number approach, it does not separate the precise effect of the HYV's themselves from other factors influencing productivity. Additional production function analyses could be most helpful in resolving these points.

There are several further steps which should be taken to complete the index number analytical package. These include, as noted earlier in this chapter, estimated research costs as well as the calculation of social rates of return. The procedure for the rate of return computations has been well demonstrated by Griliches, Evenson, Ardito Barletta, Ayer and Schuh, Hertford, Akino and Hayami, and others cited in this chapter.

This study will not detail these further steps. However, it should be recalled that the total annual investment in wheat and rice research at the international institutes in 1975 will probably be no more than $10 million. The counterpart national investment is not known, but if it is approximately the same, the total research investment is still relatively small.[36] It would appear even smaller if a lag effect were added, and the 1972/73 crop value figures linked to the research investment of several years before.[37] In comparison, the increased value of production is somewhere on the order of $1 billion. Thus the returns to investment are probably very high.

In any case, it is important to remember (as suggested in chapter II), that only part of the benefits are being evaluated. Even in evaluating direct effects, the potential influence of the HYV's in Communist nations and in developed nations has not been considered.[38] And the expanded base the improved varieties provide for future improvements has not been valued. Much remains to be measured.

* * *

More sophisticated analysis of the direct and indirect effects of the international institutes on crop production must await further study. It will not be an easy task, but the integrated use of production functions and the index number approach can help in providing a more complete evaluation of these effects.

References And Notes

[1] These approaches are introduced and described by Willis L. Peterson, "Return to Poultry Research in the United States," *Journal of Farm Economics*, August 1967, pp. 653-669; and Per Pinstrup-Anderson, "Toward a Workable Management Tool for Research Allocation in Applied Agricultural Research in Developing Countries," CIAT, June 1974, pp. 3-6.

[2] Robert Evenson, "The Green Revolution in Recent Development Experience," *American Journal of Agricultural Economics*, May 1974, p. 388.

[3] According to Evenson, one of his other studies "did not reveal a high correlation of productivity gains with the existence of irrigation infrastructure" in India (*Ibid.* p. 389). Theis may have referred to canal irrigation. In the case of tubewells it seems unlikely that a correlation would not have been found.

[4] As of early 1975, these indexes were being used by Shyamal Roy and Fred Sanderson in a study at the Brookings Institution. The indexes for 1951/52 to 1968/69, and the methodology used in their calculation, is provided in R. W. Cummings, Jr. and S. K. Ray, "1968-69 Foodgrain Production: Relative Contribution of Weather and New Technology," *Economic and Political Weekly*, New Delhi, March 29, 1969.

[5] Evenson, *op. cit.* (May 1974), pp. 387-394. Also see his paper on "Comparative Evidence on Returns to Investment in National and International Research Institutions," November 1974, pp. 15-18 (RC).

[6] Dana G. Dalrymple, *Imports and Plantings of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations*, U.S. Department of Agriculture, Foreign Economic Development Service, FEDR-14, February 1972, 56 pp.

[7] Evenson, *op. cit.* (May 1974), p. 393.

[8] Robert Evenson, "Consequences of the Green Revolution," Yale University, Department of Economics, July 1974, p. 13.

[9] Evenson reported a similar set of estimates earlier for the 1965/66 to 1970/71 period (*op. cit.*, May 1974, p. 393) but the figures were quite different and the relationship between wheat and rice reversed. It appears that some problems in this first calculation may have been corrected in making the second set reported here.

[10] Surjit Sidhu. "Economics of Technical Change in Wheat Production in the Indian Punjab," *American Journal of Agricultural Economics*, May 1974, pp. 217-226.

[11] Letter from Sidhu, University of Dar es Salaam, Tanzania, October 2, 1974.

[12] *Ibid.*, p. 219, The statement refers to regression IV in table 1 on p. 218. (*op. cit.*).

[13] Surjit S. Sidhu, "Relative Efficiency in Wheat Production in the Indian Punjab," *American Economic Review*, September 1974, pp. 743-744.

[14] Letter from Sidhu, November 12, 1974.

[15] The comparative analysis of old vs. new varieties was carried out only for 1967/68 "because during the subsequent years, the number of farms growing old wheat and the area planted to it were substantially reduced" (Sidhu *op. cit.*, May 1974, p. 217). The proportion of wheat area planted to the HYV's in the Punjab as a whole was: 1966/67, 3.6 percent; 1967/68,

35.4 percent; 1968/69, 48.5 percent, and 1969/70, 65.5 percent (p. 221).

[16] *Ibid.*, pp. 222-223.

[17] Sidhu notes that "During farm visits in 1970 and 1971 Punjab farmers generally complained of defective seed quality after 1967/68. . .I think mixing of lower quality seed with better seeds occurred at more than one level of the seed distribution channel," (*Ibid.*, May 1974, fn. 11, p. 223). Some other references to seed quality are summarized in Dana G. Dalrymple, "The Green Revolution: Past and Prospects," USAID, Bureau for Program Policy and Coordination, July 22, 1974, pp. 32-34.

[18] The seminal application was by Zvi Griliches in his study on hybrid corn. This work was reported in several journals; here I refer to "Research Costs and Social Returns: Hybrid Corn and Related Innovation," *The Journal of Political Economy*, October 1958, pp. 418-431. Major studies of the LDC's included Nicolas Ardito Barletta, "Costs and Social Benefits of Agricultural Research in Mexico," University of Chicago, Department of Economics, Ph.D. dissertation, 1970, 214 pp.; Harry W. Ayer and G. Edward Schuh, "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in Sao Paulo, Brazil," *American Journal of Agricultural Economics*, November 1972, pp. 557-569; Reed Hertford, *et al*; "Return to Agricultural Research in Colombia," January 1975, 72 pp. (RC); and Yujiro Hayami and Masakatso Akino, "Organization and Productivity of Agricultural Research Systems in Japan," October 1974, 58 pp. (RC) (subsequently published in *American Journal of Agricultural Economics*, February 1975, pp 1-10).

[19] Here I have basically adopted the simplified depiction of social benefits used by Hayami and Akino, *op. cit.*, p. 30 (also *op. cit.*, February 1975, p. 4). A similar definition of social benefits is provided by J. P. Ramalho de Castro and G. Edward Schuh, "An Emprical Test of an Economic Model for Establishing Research Priorities: A Brazil Case Study," January 1975, pp. 8-10 (RC); and Hertford, *op. cit.*, pp. 13-15. Other more complex variations are discussed in Ardito Barletta, *op. cit.*, pp. 79-84, and Ayer and Schuh, *op. cit.* (November 1972), p. 559.

[20] This formulation is taken from Pinstrup-Anderson, *op. cit.*, pp. 3-6.

[21] Griliches, *op. cit.*, pp. 419-431.

[22] Ardito Barletta, *op. cit.*, pp. 79-89.

[23] Hertford *op. cit.*, pp. 5-20.

[24] It is a reasonable question whether average farm yields are a fair way of judging the impact of the product of the institutes. Because of the influence of many other factors, as discussed in Chapter III, it might well be argued that the use of yields obtained in experimental field trails might be a more appropriate measure of the yield-related product of the institutes. These tests provide a fairly realistic estimate of the potential generated by research. Perhaps, at least, these results could provide an alternate measure of research outputs.

[25] Griliches, *op. cit.*, pp. 419-431.

[26] Ayer and Shuh, *op. cit.* (November 1972), p. 561.

[27] "A Note on the Use of Commodity-Based Studies in Estimating the Pay Off to Investment in Research," Ministry of Overseas Development, Statistics Division, London, September 1974, 7 pp.

[28] Hertford, *op. cit.*, p. 64, table 19.

[29] While pure varietal effects have reportedly been sorted out for Colombia, some rather exceptional data were available (Hertford, *op. cit.*). Use of more traditional national data on area planted to varieties and estimated quantity of analysis may produce a high degree of intercorrelation. In a study underway at the Brookings Institution in 1975, for instance, Roy and Sanderson found such a correlation (r=0.97) between the area planted to all HYV grains and estimated fertilizer use on all grains (including HYV's) in India between 1966/67 and 1973/74. In some cases fertilizer might appear to have a higher correlation with output than the HYV's. If so, this may reflect the facts that (a) the fertilizer figure usually reflects the use on both traditional and HYV crops (no one knows how much was actually used on HYV's at the aggregate level), and (b) the area of the HYV's in the early years in each country is quite small (as shown in figures 1 and 2). Hence the HYV figure may be swamped by the fertilizer figure.

[30] The ratio might well be even less in North Africa where wheat is not commonly irrigated.

[31] Excluding the People's Republic of China, North Vietnam, Japan, and Israel.

[32] Export prices per metric ton were, for example: wheat, 1972/73, \$74.60 to \$77.10; rice, 1972, \$138.40 (*FAO Commodity Review and Outlook*, 1973-74, pp. 54, 66.) The HYV's, despite improvements in taste and color, still are not exported in quantity and do not bring a premium domestic price (see, for example, Randolph Barker in "Changes in Rice Farming in Selected Areas of Asia," IRRI, January 1974 (p.6). In some countries, farm prices are held artifically low, which would unduly lower valuation of the impact at the national level. World prices began to rise sharply in 1973.

[33] An increase in output would, of course, result in a decrease in price. The amount of decrease would depend on the price elasticity of demand as well as other factors. While the price decline reduces the valuation of the added output, it is at the heart of the social benefits arising from the innovation, (as shown in fig. 9). The introduction of the improved wheats in Mexico, for instance, had a major effect in lowering prices to consumers (this matter is discussed by Jones in Dana G. Dalrymple and William I. Jones, "Evaluating the Green Revolution," USAID, Bureau for Program Policy and Coordination, processed draft, June 18, 1973, pp. 15-31). Evaluations of returns to research must give considerably more attention to the price effect.

[34] It may be of interest to note that in 1967 or 1968, Dr. Robert Chandler, then Director of IRRI, estimated that the annual value of the increase in rice production in South and Southeast Asia, at the prices then

prevailing, was on the order of $300 million ("Notes on the International Rice Research," Enclosure to Department of State Telegram A-1 96 from USUN, New York, May 15, 1968, p. 2). Evenson's estimate of the value of increased rice production in 12 Asian nations in 1967/68 was $463 million (table 6); dropping the price one-third from $100/mt to $66.67/mt would reduce the value to $309 million, close indeed considering that the estimates were undoubtedly made in quite different ways.

[35] If, for instance, HYV wheat yields of 1.75 instead of 1.50 are assumed, and overall production increase of 27.4 percent is obtained; assuming a rice yield ratio of 2.00 instead of 1.25 produces an overall production increase of 19.6 percent (table 7). A figure of 1.75 instead of 1.50 for wheat is quite possible, but an estimate of 2.00 for rice definitely seems too high (if anything, a figure of 1.25 for rice may be high).

[36] This figure would, at least in part, be composed of the Center's special projects category (noted in ch. II). In the Philippines the funds allocated to rice and other cereal food crops in the agricultural research budget proposal by the Philippine Council for Agricultural Research for the 1973/74 fiscal year was roughly $430,000 or about 8.7 percent of the 1974 IRRI budget (based on unpublished table provided by Randolph Barker, November 29, 1973). The annual expenditures on wheat research in Mexico by the Office of Special Studies between 1954 and 1960 ranged between $345,000 and $203,000 (Barletta, *op. cit*, p. 74).

[37] Recall, from footnote 8, chapter II, Evenson's use of a lag figure of 6½ years in the United States. The interval would be even greater in the LDC's.

[38] A study of the influence of the HYV's in Israel, for instance, was recently completed. It suggested that the influence of the first imports was minimal but that they did become of significance when crossed with local varieties. (Yoav Kislev and Michael Hoffman, "Research and Productivity of wheat in Israel," Hebrew University, Center for Agricultural Economic Research, Rehovot, February 1975, 22 pp.)

VI. CONCLUSION

This report has outlined the main conceptual and empirical considerations in evaluating the impact of international agricultural research on crop production in developing nations. The process has been applied to high-yielding varieties of wheat and rice.

The task of evaluation is complex. While the immediate research product can be readily identified, there are many problems in linking this product to actual changes in production in the farmers' fields. Moreover, the HYV package may have a number of indirect and qualitative results in addition to the direct and quantitative effects.

This study, after reviewing all these considerations, focused on only one measure: the direct quantitative effect. Changes in area and yield were first examined. This was followed by an analysis of the effect of the HYV's on yield, using production function and index number techniques. Even this relatively narrow focus encountered a number of analytical difficulties. Some can be solved by using the techniques in combination, rather than separately as in the past. Others are more intractable.

Despite these problems, the task is not an impossible one. Crude measures or approximations have been made, and it is certainly possible to make further improvements in evaluation. But to do so will require improved data and analytical techniques. Whether these will be forthcoming will in part depend on the need for improved analysis.

For the moment, the accomplishments of the early centers are well known. They have produced striking technologies whose worth is easy to visualize. Past studies have shown that investment in research yields high returns. And indeed this preliminary study, while not carried through to the point of calculating an actual cost-benefit ratio, suggests that the returns to international research in wheat and rice must have been very high. Perhaps these findings will be adequate for the near future.

At some point, however, it is likely that more quantitative evidence will be requested. Of all aid recipients, a research organization should be in a good position to provide some measure of its worth. It should be realized that these measures cannot be turned out overnight. Appropriate data must be available. Where data are not available arrangements must be made well in advance for their gathering and assembly. And analytical techniques must be tailored to the job at hand.

Financial resources will be needed to carry out these tasks. Perhaps one or more of the members of the Consultative Group will provide funds for this purpose in the future. Should support become available, the research could be administered in a variety of ways. The newly established International Food Policy Research Institute might play a role in this process (though this institute is not presently sponsored by the CG). The actual research, as in the past, could well involve university scholars.

In pursuing a more precise estimate of the effects of technologies, several key points have to be recognized. First, the measurement problems, as indicated, are severe. Sponsors need to have some understanding of what can and cannot be readily measured. Second, some research activities might show considerably less quantitative effect than others. Such results might not always be well received, but they ought to be known if resources are to be allocated most effectively.

It should be recognized, of course, that quantitative techniques cannot measure everything. Some research programs can be justified on other grounds. And social goals beyond productivity should certainly be considered. Rural equity issues, for example, are becoming increasingly important in the planning process.

The evaluation task, therefore, is broad and challenging. But an enlightened and effective program of international agricultural research requires research on the system itself. It is time to consider a modest but enduring organizational mechanism that can carry out the job.